HONI SOIT QUI MAL Y PENSE

MEMOIRS OF THE GEOLOGICAL SURVEY.
SCOTLAND.

THE GEOLOGY
OF
CENTRAL AND WESTERN FIFE AND KINROSS.

BEING A DESCRIPTION OF SHEET 40 AND PARTS OF SHEETS 32 AND 48 OF THE GEOLOGICAL MAP.

BY
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DIRECTOR-GENERAL.

WITH

AN APPENDIX OF FOSSILS

BY B. N. PEACH, F.R.S.

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E.V.

PREFACE.

THE present volume describes the geology of that part of Fife and Kinross which lies to the west of a line drawn from the Tay Bridge on the Firth of Tay to Scoonie Links on the Firth of Forth. The ground was mapped on the scale of six inches to a mile by different members of the Geological Survey, when Sir R. I. Murchison was Director-General and Professor A. C. Ramsay, Local Director. Mr. H. H. Howell surveyed the area westward as far as Newburgh, Auchtermuchty, the east end of Loch Leven, Auchtertool, and Seafield Tower. Professor James Geikie took the hilly district along the borders of the two counties of Kinross and Perth between Auchtenny and Auldie Castle. Professor John Young mapped the northern slopes and low ground between Dunning and Newburgh. Mr. B. N. Peach surveyed that part of the Ochil ridge which is traversed by the county boundary between Dochrie Hill and Auchtermuchty. The area from Seafield Tower westwards to Torryburn, and northwards to the watershed of the Ochil Hills above Milnathort was mapped by myself.

No descriptive Memoir having been issued by the Survey in illustration of this tract of country, I have prepared the present account, which will serve as an Explanation to Sheet 40 of the Geological map and to the southern part of Sheet 48 as far east as the Tay Bridge. It comprises the centre and west of Fife, with the whole of Kinross-shire and the eastern margin of the county of Perth between Dunning and the Firth of Forth. In writing the following chapters I have availed myself of the work of my colleagues as recorded in their field-maps, and of abundant notes which I have myself made at different times in traverses of the ground. It will be understood that the authority for the main facts from each district rests on the basis of the surveys by the officers above named.

The coal-fields have been in late years re-visited by Mr. J. S. Grant Wilson, who has revised parts of the map and has collected a considerable amount of information regarding mining and boring operations since the date of the original survey. This information is to a large extent embodied in the chapters descriptive of the different coal-fields.

The palæontological details in the following chapters have been revised by Mr. B. N. Peach, who has superintended the preparation of the valuable Lists of Fossils given in the Appendix. Among those to whom a special acknowledgment of indebtedness is due

for assistance freely rendered, a first place must be found for Mr. J. W. Kirkby, who has placed at the service of the Survey the results of his long and intimate acquaintance with the stratigraphy and palæontology of the Carboniferous Series of Fife. The materials so generously supplied by him have been incorporated in the Lists of Fossils given in the Appendix, and I have further availed myself of notes which he has furnished, and which will be found to form an important part of the description of the Dysart Coal-field given in Chapters XIV. and XV. Dr. Traquair has greatly aided us in the determination of the fossil fish, Dr. Wheelton Hind in the examination of the lamellibranchs, and Mr. Robert Kidston in the discrimination of the plants.

Mr. Herbert Kynaston, one of the staff of the Geological Survey in Scotland, has studied the microscopic structure of the igneous rocks of the Lower Old Red Sandstone, and his notes are partly embodied in Chapter III. and fully given in Part II. of the Appendix. The general petrography of the Carboniferous igneous rocks, so far as comprised in this volume, is based on the studies of Dr. F. Hatch and Professor Watts.

Part III. of the Appendix, consisting of a Bibliography of writings in which the geology of the region described in this volume is discussed or alluded to, has been prepared by Mr. D. Tait.

ARCH. GEIKIE,
Director-General

Geological Survey Office,
Jermyn Street, London,
1st June 1900.

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OF

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CHAPTER I.

INTRODUCTORY.

Area Described—Form of the Ground—Relations of Topography and Geology—Streams and their Valleys—Lakes—Coast-lines—Vegetation and Soils.

THE part of Scotland which will be geologically described in the following pages embraces the central and western parts of the county of Fife, as far towards the east as a line drawn from the Tay Bridge southward by Cupar and Ceres to the Firth of Forth in Largo Bay. It includes also the whole of Kinross-shire and, for the sake of geological completeness, a narrow strip along the south-eastern borders of Perthshire. The district thus circumscribed is nearly all included in Sheet 40 of the Geological Survey Map of Scotland, but a portion of it, extending up to the Firth of Tay, is contained in Sheet 48, while the southern projection of the land to Queensferry is embraced in Sheet 32. The remaining portion of Fife will be the subject of a separate Memoir on the eastern district of the county.

It will be seen that the country to be treated of in the present volume includes one of the most populous and industrial centres of Scotland. Lying between two of the great estuaries of the Kingdom, and washed on all sides but one by tidal waters, it has from early times played an important part in the seafaring life of Scotland. Possessing a succession of coal-fields throughout its entire length, it has long taken no inconsiderable share in the mineral development of the country. Its long ranges of pastoral hills have furnished excellent ground for the rearing of sheep and cattle, while the fertile soil of its valleys and seaward slopes has been

assiduously and successfully cultivated. Its coal-producing tracts have risen into thickly-inhabited centres of population. The indentations cut by the sea or by rivers in its coast-line have become harbours, where for many generations active and hardy fisher-folk have plied their trade, and whence coal has been exported in ever-increasing quantity to the Continent.

Much of this prosperity is distinctly traceable to the favourable geological conditions in which the people have been placed. These conditions depend on structures and processes which cannot be briefly described. In so far as they have been concerned in the development of central and western Fife, a somewhat detailed account of them will be found in the present volume.

FORM OF THE GROUND.—It will be seen from the distribution of the colours which represent the geological formations on the Sheets of the geological map that this region consists essentially of three broad bands which run, on the whole, parallel to each other, in a general north-east and south-west direction. This arrangement of the colours gives the key to the topography, which may be said to consist of two belts of hilly country separated by a central tract of lower ground.

The north-western belt embraces the central and nearly the whole of the eastern part of the long range of the Ochil Hills. This ridge, which forms so prominent a feature in the scenery of the great midland valley of Scotland, reaches its highest point (2363 feet) about seven miles to the west of the limits of the region now to be described. From that culminating summit the uplands gradually sink in level as they extend towards the north-east. Where they enter our district their highest crests have already subsided to from 1500 to 1700 feet, but where they leave it they are generally less than 400 and seldom exceed 500 feet. The breadth of this belt of hills, between the plains of Kinross-shire and the Howe of Fife on the south side and the southern margin of the Firth of Tay on the north, is about six miles.

The general aspect of the Ochil Hills is smooth and green. For the most part the rocks have been worn by the various forces of denudation into gentle slopes and rounded summits, which are covered with pasture and heath. Crags and bare scars are comparatively scarce throughout most of the range, though naked rock comes out in lines of bold cliff-escarpments among the northern and western hills and in endless hummocks on the lower grounds further to the east. The general dip of the rocks throughout most of the district being to the south-east, they present their edges to the opposite quarter, and as they succeed each other sometimes with considerable regularity, their successive step-like terraces and cliffs near sea-level have been mistaken by some observers for lines of old sea-margin. This deceptive appearance is especially well marked along some parts of the ground that descend steeply into the estuary of the Tay.

While the successive parallel ridges of the Ochil Hills correspond,

on the whole, with the general strike of their component rocks—that is from south-west to north-east—most of the valleys are of the transverse order, and the streams which flow in them descend either towards the south-east into the central lowland or towards the north-west into Strath Earn. But there are also, especially on the north-western side of the watershed, a number of longitudinal valleys which correspond in direction with the prevalent trend of the ridges. The same valley may be longitudinal in one part of its course and transverse in another. Thus the Water of May runs for the first five miles of its journey in a longitudinal valley until, at the Mains of Condie, it turns in a transverse direction to the Earn. The most picturesque of the valleys in the Ochil range, that known as Glen Farg, is an illustration of this union of the two trends, and also an example of a continuous trench excavated across the high grounds. On the southern side, the ground for several miles rises only a few feet from the plain around Loch Leven to the watershed near Damhead, where it is about 480 feet above the sea. But from that point the Glen Farg valley strikes obliquely across the chain of the Ochils in a north-easterly direction as a narrow rocky defile until above Greenend it suddenly emerges from the hills and enters the alluvial plain of the Earn, which is only about 50 feet above the sea. It is through this defile that the Great North Road runs, and that the line of railway has been led from Edinburgh by the Forth Bridge to Perth and the north. Another instance of a continuous depression across the Ochil range is furnished by the valley, or succession of valleys, along which the road runs from Yetts of Muckhart to Dunning.

The central lowland between the Ochils on the north and the disconnected groups of the Cleish, Lomond, and Kettle Hills on the south forms part of the marked depression known as the Howe of Fife, which extends from the south-west of the county of Kinross for a distance of nearly thirty miles to the sea in St. Andrews Bay. The portion of this important topographical feature included in the area now under description embraces its western and broadest part. Where it enters the district on the north-east at Cupar, the vale is not more than about a mile and a half broad, and its surface has a general elevation of little more than 100 feet above the sea, which is some six miles distant. South-westward it expands between Auchtermuchty and Freuchie to a breadth of nearly five miles, but so little does the plain rise in elevation that even ten miles further on it is less than 200 feet above sea-level. At Strathmiglo, by the projection of the northern spurs of the Lomond Hills, the vale is again narrowed to a mere strip chiefly occupied by the alluvial plain of the river Eden and not a mile in breadth. Beyond this constriction the depression sweeps south-westwards, and soon expands into the wide plain of Kinross-shire, which, circling round the base of the West Lomond, Bishop, Benarty, Cleish, and Ochil heights, attains a breadth of some six miles. This great enlargement of the Howe of Fife contains Loch Leven, which, with its surrounding strip of alluvium, marking a former

bottom of the water, covers an area of nearly twelve square miles. If the general level of the plain of Kinross be taken at 400 feet, then the average rise of the hollow from the sea to its termination is little more than 13 feet in a mile.

The southern belt of hilly ground in central and western Fife is much the most varied tract in the district. Instead of a continuous band of uplands, like the Ochils, it presents numerous groups of hills and detached eminences which, though somewhat irregularly distributed, maintain nevertheless, on the whole, the prevalent trend of the region from south-west to north-east. Viewed in the broadest way, this part of the district may be regarded as comprising an assemblage of detached and prominent hills, gathered along its northern margin, where it rises from the Howe of Fife and the plains of Kinross, of a parallel belt of isolated and confluent ridges of much lower elevation, beginning above Kirkcaldy and extending south-westwards to Queensferry, and of scattered eminences which diversify the lowland that separates these two more hilly tracts.

Of the northern belt of hills the most important and conspicuous is the group of the West and East Lomonds, which rise to heights of 1713 and 1470 feet, and form prominent landmarks all over the eastern part of the midland region of Scotland. To the east of these, a group of hills, ranging from 600 to 700 feet, stretches from Freuchie and Kennoway north-eastwards to near St. Andrews. To the south and south-west of the Lomond and Bishop group, the ridge that overlooks Loch Leven mounts into a number of separate heights. Of these the highest, Benarty (1167 feet), forms a noble boundary to the southern margin of the lake. Further west lie the Blairadam, Cleish, Cult, and Saline Hills (1178 feet), from which the ground descends into the plains of Clackmannan. Throughout this belt of hilly ground the topographical features are more accentuated than in most of the Ochil region. The hills frequently rise abruptly from the lower country around them, often present precipitous crags, and occasionally display picturesque ranges of escarpment, as in the Lomonds and Benarty.

In the stretch of hilly ground between Kirkcaldy and Queensferry, there is a more continuous grouping of heights than in the northern belt just described. It may be said that a scarcely interrupted ridge runs from the Raith Hills south-westwards by Auchtertool and the Cullalo Hills to Inverkeithing. But besides these more persistent tracts of higher ground, this part of the district abounds in prominent detached eminences which form characteristic elements in the landscapes between Kinghorn and Aberdour. The Binn of Burntisland (631 feet) and Dunearn Hill (727 feet) may be taken as two of the most conspicuous examples of these topographical features.

The largest tract of low ground in the southern half of the district is that which extends from the Kirkcaldy hills north-eastward to the hills beyond Markinch, Kennoway, and Leven. This important tract includes the Kirkcaldy and Dysart coalfields, and is unbroken by any of the ridges and hills that diversify the

surface all around it. It is prolonged south-westwards between the Raith and Cullalo Hills on the one side and those of Auchterderran and Blairadam on the other. But in this extension it no longer retains the same unbroken lowland character, for it is interrupted by detached ridges and isolated hills, like those of Cowdenbeath, Halbeath, Roscobie, and Luscar.

RELATIONS OF TOPOGRAPHY AND GEOLOGY.—The topographical features which have here been enumerated, like those of the rest of the midlands of Scotland, furnish admirable illustrations of the close dependence of such features upon geological structure. The fundamental law which has governed the evolution of the scenery has been that relative durability of material determines the shaping of the contours of the land; in other words, that as the present surface has been produced by prolonged denudation, the rocks which have been best able to withstand degradation have been left projecting above those endowed with less power of resistance, which have been hollowed into valleys and plains. Except indirectly, underground disturbances cannot be shown to have affected the development of the landscapes as these appear to-day. Although the district abounds in volcanic rocks no single part of the present topography dates from the time of the volcanic activity. The lava and tuffs after their eruption were buried under hundreds or even thousands of feet of stratified deposits, and their ultimate re-appearance at the surface has been the result of stupendous denudation, whereby their deep overlying cover of younger rocks has been removed. Again, the rocks have everywhere been affected by dislocation of the terrestrial crust, and are now traversed by faults which show displacements of 1200 feet or more. But these important fractures have not given rise to yawning rents, chasms, or cliffs. For the most part, they have not affected the present surface of the ground at all. In the coal-fields, for example, where the position and effects of the dislocations have been carefully ascertained during mining operations, one may walk over the sites of some of the most important faults without being able to perceive the slightest surface indication of their existence. Here and there, indeed, where a fault has brought down a comparatively soft against a comparatively hard rock, a sharp rise of the ground may be seen along one side of the line of fracture, such as the great southern wall of the Ochil chain rising above the plain of the Clackmannan coal-field. But even in such instances the effect of the movement has only been indirect. What we now see is not any original step-like interruption of the ancient surface, but is due to the prevalent law that the harder rocks project above the softer. All that can be attributed to the fault is the determination of the direction of boundary of the two rocks, and consequently of the topographical feature which has resulted from their unequal decay.

The Ochil Hills, consisting for the most part of hard volcanic rocks belonging to the time of the Lower Old Red Sandstone, rise as a broad belt of upland above the softer stratified formations

on each side of them. The various detached and confluent ridges and eminences in the belt of hilly ground lying to the south of Loch Leven and the Howe of Fife also consist of various igneous rocks, but of a different type and age from those of the Ochils. Their position and outlines coincide with the area and nature of the erupted masses that form them. On the other hand, the lower grounds lie mainly upon stratified rocks which offer less resistance to waste. Thus, the long depression of Kinross and the Howe of Fife has been hollowed out of the comparatively unresisting red sandstones which overlie the durable lavas of the Ochil chain on the one hand, and pass under the hard eruptive sheets of the Lomond belt on the other.

STREAMS AND THEIR VALLEYS.—During the long process of denudation, the waters running off the land have carved out lines of valley for themselves in their passage to the sea. In the present area, a vast number of such water-channels has been excavated, but none of them has sufficient length and gathering-ground to have become the bed of an important river. The chief stream is the Eden, which, rising among the slopes of the Ochil chain, about two miles north from Milnathort, flows through the whole of the long Howe of Fife and falls into the sea in St. Andrews Bay. The west side of the district takes in a small portion of the course of the Devon, which drains a considerable tract of the Central Ochils. Loch Leven, owing to a gap having been worn through the Benarty and Lomond Hills, does not drain into the Howe of Fife, to which geologically its plain belongs, but sends its water by the Leven river eastwards to the Firth at Leven. The hollow between the Auchterderran and Auchtertool Hills gives passage to the drainage from the east side of the Cleish and Roscobie Hills, which is conducted by the Ore into the Leven about three miles above its mouth.

The topography of the whole region has been profoundly modified by the geological events of the Ice Age. So thick was the mass of ice which then descended from the Highlands, that it passed over the lofty ridge of the Ochils and the other hills to the south, and turned eastwards into what is now the Firth of Forth and the North Sea. By the long-continued movement of this ice-sheet, the exposed rocks were rubbed down, scored, and polished, and their surfaces acquired that undulating character still so distinctive of them. Not only were their ruggednesses smoothed away, but the decomposed material, accumulated upon them in the course of long ages of subaerial decay, was ground up or moved onward by the ice, which spread it in thick deposits all over the low grounds. These deposits, known as Drift, conceal most of the solid rocks, except where these rocks rise into prominent heights. They fill up all the hollows and extend under the firth, where they reach a thickness of sometimes nearly two hundred feet.

LAKES.—In central and western Fife and Kinross-shire a few lakes diversify the surface of the country. Of these the most important is Loch Leven—the largest sheet of fresh water in the

midland valley of Scotland. In the north, among the hollows of the Ochil chain, lies the Loch of Lindores. Among the Cleish Hills, Loch Glow is nearly surrounded with peat-mosses. On the lower grounds a number of smaller sheets of water lie between the Cleish Hills and Kirkcaldy. Such are Loch Fitty, Loch Gelly, Camilla Loch, Otterstone Loch, and Kinghorn Loch. But, as will be more fully explained in Chapter XIX., the present lakes are only the last survivors of a vast number that once were scattered broadcast over this region. As in the rest of the lowlands of Scotland, the former abundant lochs and tarns have here almost wholly vanished, partly from natural causes and partly from the operations of man.

COAST-LINES.—Upwards of 30 miles of the northern coast-line of the Firth of Forth are included in the present district, between Valleyfield and Scoonie Links. Though these shores are generally low they afford excellent sections of the rocks for most of the distance. Here and there, they rise into cliffs, of which the most conspicuous are those formed by the igneous rocks. On the south-west rise the picturesque crags of North Queensferry. Further east the tuff of St. David's stands up as a long coast-cliff, while a little beyond these precipices one of the diabase sills of Aberdour runs out to sea as a rocky promontory. Similar headlands were once more conspicuous at Burntisland than they now are, owing to the enlargement of the harbour, and the works connected with the railway station. To the east of Burntisland the coast reaches its highest part in the crags of Pettycur and Kinghorn. Here the ground rapidly ascends by escarpments and grassy slopes to a height of 377 feet above King Alexander's Crag, and projects seawards in a series of cliffs and skerries which afford admirable sections of the volcanic rocks that form so marked a feature in the Lower Carboniferous series of this part of central Scotland. From Kinghorn to Linktown the interstratification of the volcanic sheets and intrusive sills in the limestone series is well displayed in shore-reefs that are exposed between tide-marks. Beyond the sandy beach of Kirkcaldy, the shore once more becomes rocky, and from Pathhead north-eastward for seven miles presents a succession of rocky ledges and out-jutting promontories, in which the upward sequence of the Carboniferous system can be followed almost bed by bed. Above these strata, the ground rises as a steep bank of boulder-clay from the line of high water to a height of 100 feet. At East Wemyss, the red sandstones form a line of low cliff beneath the boulder-clay, along the inner margin of the beach. In this cliff, when the land stood at a lower level, the sea excavated the group of caves from which Wemyss takes its Celtic name. From Buckhaven north-eastwards, the old coast-line, which will be afterwards more fully described, begins to retire from the line of the present beach, and a strip of blown sand, intervening between it and high-water mark, forms a band of links that stretches for about four miles as far as Largo. But the upper Coal-measure strata still continue to make shore-ledges from Buckhaven to Leven and reappear at Lundin and Largo.

In connection with the coast-line of the Firth of Forth, allusion may be made here to the proofs, which will be more fully given in a later part of this volume, that the sea has made considerable inroads on the land during historic times, and that its progress can be shown at many places by recent raw scars, where portions of the cliffs have been undermined and have given way. Among the many instructive lessons which these shores afford to the geologist, some of the most impressive are those which tell the story of the destructive action of the waves.

The central portion of Fife likewise includes the southern coast-line of the Firth of Tay from Newburgh to Newport—a distance of about twelve miles. Neither from a pictorial nor from a geological point of view is this shore so varied and interesting as that of the Forth. It is straight and destitute of indentations. The alluvial silt of the Firth spreads over the beach up even to high-water mark. A narrow strip of low, drift-covered ground intervenes between the shore and the base of the steep slopes into which the volcanic rocks of the Ochil range rise. Here and there, as immediately above Newburgh, where a gap has been cut in the line of escarpment, some variety of outline is introduced, and the rocks that tower steeply above the village, to which they present their escarpments, show on their eastern declivities a notable series of parallel ribs of rock slanting in a south-easterly direction into the interior.

The geological variety of this coast-line is extremely limited. As the line of the estuary coincides with that of the strike, the same rocks continue along nearly the whole way. But they are only well exposed on the shore at Birkhill, and still more picturesquely between Balmerino and Newport.

Vegetation and Soils.—While the general form of the ground is dependent upon the geological structure of the rocks underneath the surface, the outward aspect of that surface is greatly affected by the varying nature of the soils and the consequent character of the vegetation. On the hills where the rocks come unconcealed to daylight, the soils are directly derived from the decomposition of the solid rock underneath. But in the valleys or the plains, and generally over the slopes and lower grounds, the soils have little or no immediate relation to the solid rocks, but have been formed out of the various drift deposits under which the rocks are buried. These differences in the composition and quality of the soils have determined the character of the vegetable covering of the country.

Thus, over the range of the Ochil Hills, on the tops of the ridges and the upper parts of the slopes, the volcanic rocks appear in knolls and crags, or are concealed under a thin mantle of their own detritus. The soil to which they give rise is generally light, and supports on these uplands a covering of pasture and heather. Where, however, the higher ground sinks into slopes and valleys under boulder-clay, it is covered, over the unenclosed land, with a stiff retentive soil, not unusually distinguished by its

abundance of rushes and other moisture-loving plants. The progress of agriculture has done much, by drainage and ploughing during the present century, to reclaim tracts of both these types of soil, which had previously existed only as bare moors and wet hillsides. The southern slopes of the Ochils now display a continuous succession of farms, the plough has by each generation been driven higher up the hills, and fields enclosed with walls have crept upward to heights of more than 1000 feet above the sea. Much of this land, however, which was formerly kept in green crops and corn, is now retained as permanent pasture.

On the uplands none of the natural forest has survived which, no doubt, at one time extensively clothed them, though here and there among the still unreclaimed "muirs" (moors) an occasional group of birches, willows, or Scotch firs serves to indicate what the natural woodlands once were. But artificial plantations, chiefly of conifers, have been made, and now cover wide tracts of ground. Some of the largest of these may be seen in the districts traversed by the Farg and the Water of May, and on the southern slopes between Carnbo and Duncrevie. A number of these plantations have been carried to heights exceeding 1000 feet. Thus, the Auchtenny Wood, which overlooks the valley of the Water of May, rises to more than 1200 feet.

The irregular groups of hills which form the long broken range from Saline and Carnock eastwards by the Lomonds to the north-east corner of the map differ in many respects from the chain of the Ochils, and in none more than in the nature and distribution of their soils. Instead of forming the main mass of continuous high ground, as in the Ochils, the igneous rocks here occur only in scattered isolated sheets and bosses, which rise out of the surrounding stratified formations. In the great majority of cases, the flanks of these projecting eminences are concealed under boulder-clay, which sweeps across all the surrounding lower ground The igneous material, where it is exposed to the weather, decomposes into a warm, fertile, rich brown loam, which, from the frequent presence of apatite in the rocks, furnishes a supply of phosphate of lime to the soil. Where these rocks come to the surface on gentle slopes, and directly form the subsoil, they produce by much the richest soils in the district. Under favourable conditions, we may recognise, even from a distance, the boundary between the igneous mass and the surrounding mantle of boulder-clay, by the contrast between the vegetation on the two surfaces. The igneous rock is carpeted with bright green grass, through which the dark-brown hummocks and crags of decomposing rock protrude. The boulder-clay, on the other hand, unless where it has been long drained and ploughed, has its limits marked by the smoother and darker slopes of rushy vegetation.

Over most of the lowland the stratified rocks seldom form any prominent surface-features. Where the ground slopes most steeply, the strata sometimes come out in successive bars of naked stone, as in the declivities below the West Lomond and Benarty.

It is chiefly in the course of the streams, and along the coast-line, that the stratified formations impart a distinctive character to the landscape. Elsewhere they are for the most part buried under drift.

The two great subdivisions of the Drift Deposits—boulder-clays and sands and gravels—which exercise so important an influence on the nature of the soil, have in two directions powerfully affected the outer aspect of the ground. The boulder-clay, as already stated, furnishes stiff retentive soils which, where they remain unreclaimed, are marked by a rank, mossy and reedy vegetation. But where they have been properly treated, they have been so greatly modified and improved by long-continued cultivation as now to afford excellent corn land. Most of the arable ground in the district is of this nature. But in the larger valleys and also along the sea-margin the boulder-clay is more or less covered by deposits of sand and gravel, which have given rise to soils of a totally different quality. Thus, in the Howe of Fife, a thick mantle of these upper drifts stretches up as far as Strathmiglo. The plains of Kinross are likewise covered with them, and similar accumulations extend westwards into the low grounds of Clackmannanshire. The surface of the ground where it is formed by the sands and gravels is generally a good deal more irregular than where it lies on boulder-clay, for the upper drifts are often arranged in mounds and ridges, with hollows between them either filled with water or covered with the peat that marks former tarns or lakelets. Some excellent examples of these topographical features may be seen around Coldrain, two miles to the south-west of the town of Kinross. As may be inferred from their component materials, the upper drifts form the lightest soils of the district. These soils vary from sandy loam into a slightly loamy sand. Where the sand has accumulated near the sea-shore and been blown by winds into dunes, it furnishes a fitting soil for the various sand-loving plants of our coasts, and under its covering of bent and short grass has spread out in the "links," now so largely resorted to for the pastime of golf.

It must always be remembered that the progress of agriculture has vastly altered the general aspect of the country. Two hundred years ago wide tracts of ground, which are now covered with cultivated fields and abound with farms, hamlets, and villages, were bare moorland, wholly unreclaimed and tenanted by grouse and moor-fowl. Such were the various "muirs" which covered so large a part of Fife, as the Forthridge Muirs, north of Inverkeithing; the Muir of Dysart, the Bishop's Muir, north of the Bishop's Hill; Strath Kinness Muir, Outh Muir, Lethans Muir, Roscobie Muir, Thriepmuir, Moors of Kinnesswood, Moors of Balgeddie, Ceres Moor, Carnock Moor, Dirley Moor, Grantsmoor, and many more. On Pont's map of Fife sparsely-peopled areas are distinctly marked, while at the same time a more advanced condition of agriculture is shown by the names crowded together on the fertile lands that slope to the sea, and that lie along the main valleys like

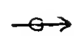
those of the Eden and Leven. Some relics of this primitive aspect of the country still survive. The Tents Muir, with its sand-dunes and covering of bent, has undergone little further change than the gradual encroachment of agriculture along its western borders. Of the Priors' Muir, to the south-east of St. Andrews, a small tract of heath, dotted with willows in its moister hollows, and with gorse on its drier ground, remains as a memorial of the olden time. A reminiscence of the former aspect of the county is preserved in abundant place-names scattered all over Fife, such as Muirhead, Muirfield, Muirton, Muirside, Muirend, and others.

CHAPTER II.

Formations and Groups of Rock and General Geological Structure of the District.

THE geological formations contained within the district are indicated on the side of the maps and may be grouped in stratigraphical order as in the subjoined table, the aqueous and igneous series being kept distinct from each other.

AQUEOUS.

			Sign on Maps.
Recent and Post-Tertiary.	Blown sand	Subaerial and fresh water.	
	Alluvium of stream-terraces and old lakes		
	Peat		
	Mud and sand of present beach	Estuarine & marine	
	Raised beaches (25 feet) . .		
	,, (100 feet) .		shaded yellow line.
Drift Series.	Sands, gravels, and stratified clays . .		
	Erratic blocks		
	Boulder-clay or till		
	Ice-markings on rocks		
Carboniferous.	Upper Red Sandstone group . . .		$d^{5'}$
	Coal-measures		d^5
	Millstone grit		d^4
	Carboniferous Limestone series.	Upper Limestone group, Coal-bearing group, Lower Limestone group	d^2
	Calciferous Sandstone series.	Burdiehouse Limestone group	$d^{1'}$
		Cement-stone group .	d^1
Old Red Sandstone.	Upper Yellow Sandstones (Dura Den beds) and Red Sandstones, marls, and conglomerates		c^3
	Lower Red Sandstones and conglomerates, with thick volcanic series .		c^1

IGNEOUS.

A. *Interstratified, or contemporaneous with the formations among which they lie.*

In Carboniferous system.	Dolerite, Basalt, Diabase, as intercalated sheets of lava	Bd^1
	Andesite, Trachyte, lying above "Cement-stone group"	Pd^1
	Volcanic tuffs (of basic character) . .	Ts d
	Agglomerate in necks or volcanic chimneys	N d
In Lower Old Red Sandst'ne	Andesites and associated lavas . .	$P\ c^1$
	Agglomerates, tuffs, and volcanic conglomerates.	$Ts\ c^1$

B. *Intrusive, or subsequent in date to the formations among which they lie.*

Basalt and dolerite in dykes, sills, and bosses	Gn. B
Felsites of various types	F

The threefold arrangement of the topographical features of the district, noticed in the previous chapter, and their disposition in parallel bands trending in a north-easterly direction, afford the clue to the broad geological structure of the ground. Two main geological systems are seen to be here represented—the Old Red Sandstone and the Carboniferous. The former includes the northern or Ochil range of hills, together with the Howe of Fife and the Kinross-shire plain; the latter embraces all the rest of the ground southward to the margin of the Firth. The Old Red Sandstone system is tolerably uniform and persistent in the nature and development of its rocks. Consequently its hard igneous masses form the long continuous uplands of the Ochils, whilst its soft sandstones underlie the plain of Kinross and the Howe of Fife. The Carboniferous system, however, is much more varied in the character and grouping of its constituent members, and thus presents a greatly more diversified topography. Though it conforms to the general north-easterly trend of the formations, the strike of its several subdivisions is found to present continual changes of direction, since the strata have been thrown into many basins, and their structure has been further complicated by numerous and often powerful dislocations. It will be observed that these disturbances do not seem to have affected the Old Red Sandstone area, at least they have not yet been traced therein, though possibly if the strata underneath the surface had been there as fully explored as those of the coal-fields have been, the geological structure would not have proved altogether so simple.

The boundary-line between the two systems runs continuously across the map from the Rumbling Bridge on the west to the extreme north-eastern corner. The western half of this boundary is produced by a line of fault, but the eastern half is a natural junction formed by the superposition of the base of the one system conformably upon the top of the other. At only one part of the boundary do the two systems encroach on each other by each crossing the fault. The large dislocation which passes to the south of Benarty allows a portion of the Lower Carboniferous strata to appear on its northern side and a strip of the uppermost yellow and red beds of the Upper Old Red Sandstone to intervene between the Carboniferous outlier and the main mass of the coal-bearing series to the south.

In the following descriptions the several stratified formations are taken in stratigraphical order, beginning with the oldest.

CHAPTER III.

Lower Old Red Sandstone.

THE representatives of this geological system consist of two distinct subdivisions—Lower and Upper—each of which is largely developed in Central Scotland, and supplies in Central and Western Fife and Kinross-shire excellent illustrations of its typical characters.

The Lower Old Red Sandstone of the midland valley of Scotland consists mainly of dull purplish-red sandstones and conglomerates, which attain a thickness of several thousand feet. Among these sediments of an ancient lake or inland sea are intercalated, through certain strips of country, thick accumulations of lavas and tuffs, which prove that long-continued volcanic eruptions took place from different vents along the floor of that sheet of water. The material so discharged now forms long lines of upland that rise into some of the most conspicuous features of the Lowland topography. One of these chains of heights is seen in the Pentland Hills to the south of Edinburgh. Another constitutes the still loftier and longer range of the Ochil Hills. It is a portion of this latter range which comes into the district now to be described.

The first observation that may be made regarding the Lower Old Red Sandstone of this district is that sandstone, or ordinary sedimentary rock of any kind, is singularly scarce. The whole series is eminently volcanic, being built up of a vast succession of sheets of agglomerate and lava, with occasional intercalations of tuffs and volcanic conglomerates. The base of this volcanic pile is nowhere visible, though its upper members can be seen to pass under the thick mass of red sandstones which underlies Strath Earn. Hence its total thickness cannot be determined. But where most largely developed, in the western portion of the Ochil chain, it must exceed 6500 feet.

In order to appreciate the geological structure of the ground and the volcanic history now to be traced, it is necessary to note that the volcanic rocks of the Ochils are arranged in the form of a broad or flattened anticlinal arch, the axis of which runs obliquely across the chain in a north-easterly direction, from the eastern end of the Clackmannan coal-field near Muckhart to the alluvial plain below Bridge of Earn. The lowest rocks are to be seen along the crest of the fold, where they have been laid bare by the erosion of the valleys excavated in them. The highest members of the volcanic series are visible on the north-west side, where, from Forgandenny and Forteviot south-westward by Dunning, Auchterarder, Sheriff Muir, and Bridge of Allan, they sink under a thick series of red sandstones in Strath Earn and Strath Allan.

The lavas consist chiefly of the varieties of somewhat altered andesite which were formerly included under the general term "porphyrite." Where fresh they are close-grained, compact rocks, often distinguished by the abundance of their porphyritic felspars and also by the frequency and great development of their cellular structure. Their general colour as they weather on the hillsides is some tint of purplish-red, but they shade on the one hand into pale pinkish-grey varieties, and on the other through tints of green and brown to dark brown or almost black. When examined under the microscope, they are seen to possess the characteristic felted microlitic groundmass of the andesites. Their porphyritic constituents are for the most part plagioclase felspars, sometimes in flat tabular crystals half an inch or more in diameter; but enstatite, augite, olivine, and black mica also occur, the olivine often in the form of hæmatitic pseudomorphs, which on a fresh fracture have a metallic lustre and readily yield a bright-red streak. The andesites occasionally assume a resinous texture, as in a remarkable pitchstone-like rock which occurs above Airthrey Castle, near Bridge of Allan, and in rare instances their intrusive varieties have even retained a vitreous or obsidian-like character, like the example described by Messrs. Durham and Judd from Newport. *

The vesicles in the andesites have been filled up with calcite, zeolites, agates, and other minerals which have acquired for certain localities a wide reputation on account of the variety and beauty of the specimens which they have yielded. Glen Farg has been specially famous in this respect from its accessibility (the great north road to Perth, as well as a modern main line of railway, passes through it), and from the abundant exposures of its amygdaloids.

While andesites of intermediate or even of somewhat basic composition constitute the great mass of the lavas of the Ochil Hills, they occasionally alternate with pale pink or yellow felsitic rocks of much more acid character. These are generally somewhat decayed, but they often retain in great perfection their original flow-structure. That they are true contemporaneously erupted lavas and not intrusive sills is proved by the abundant fragments of them contained in the intercalated conglomerates and sandstones. Some of these more acid lavas are allied to the rhyolites; others may be classed as dacites. Rocks of these types may be seen on the shores of the Firth of Tay west of Wormit Bay. They are also extensively developed in the ground around Craig Rossie and Rossie Law to the east of Auchterarder. (Sheet 39.)

This remarkable alternation of comparatively basic with much more acid material in the same volcanic field among the eruptions of Lower Old Red Sandstone time was first noticed in the Pentland Hills, and has been subsequently observed in the other volcanic areas of the same geological period.

While the lavas form the main mass of the volcanic pile, they are accompanied with frequent intercalations of fragmental

* Quart. Journ. Geol. Soc., Vol. xlii. (1886), p. 418.

material, due mainly to volcanic explosions, but partly also to the denudation of the materials of previous eruptions, and less frequently to the deposition of ordinary sandy sediment. The tuffs vary in texture from fine pyroclastic detritus to coarse agglomerates composed of blocks of which some in Dumyat, near Stirling, are as large as cottages. While most of the tuffs have been derived from the explosion of the prevalent andesites, it is to be remarked that, in the Ochils as in the Pentland Hills, some of them consist of pale felsitic detritus, even when they are intercalated between andesites. In these cases they have evidently been derived from the explosion of a felsitic magma which may not always have reached the surface in streams of lava. A characteristic feature of the fragmental deposits is the occurrence among them of coarse volcanic conglomerates, derived wholly or in great part from the destruction of banks of lava or scoriæ by the action of waves or currents during intervals between successive eruptions. Some of the sandstones also have been in great part formed of volcanic detritus. Thus, at Wormit Bay, on the Firth of Tay, a thick group of sandstones has been in large measure derived from the waste of a pink orthophyric lava-sheet which underlies them, and partly perhaps from volcanic explosions of orthophyric material. The remarkable rocks of Craig Rossie, near Auchterarder, are overlain by a breccia or conglomerate made up in great part of their detritus mixed with ordinary sandy sediment.

Besides the rocks which have been ejected to the surface during the volcanic period of the Lower Old Red Sandstone, there occur also numerous intrusive masses which have invaded both the lavas and tuffs. The great majority of these, though, of course, later than the rocks which they immediately traverse, obviously belong to the general volcanic series. They mark some of the subterranean injections of the igneous magmas, and no doubt represent different stages in the differentiation of these materials. They are partly andesites, usually more compact and on the whole less basic than the lavas. They are not as a rule vesicular. Some of them of considerably more acid composition may be classed as orthoclase-felsites or orthophyres. They may also include some rocks that might best be classed with the trachytes. They occur in large and small bosses, sills, dykes, and veins. An important group of them lies among the hills to the north-east of Fossaway and Carnbo. A remarkable sill occurs near the base of the volcanic series at Newburgh.

In addition to these intermediate and more acid intrusions, a few bosses and dykes must be mentioned, the age of which cannot be precisely defined, but which may with probability be regarded as more deep-seated portions of the magma which supplied the general body of andesitic lavas of the volcanic period of the Lower Old Red Sandstone. They consist of dark more or less coarsely-crystalline "greenstones." The largest of them rises through the general mass of lavas at Duncrevie, and is a rudely circular boss nearly half a mile in diameter. Microscopic examination of this

rock by Mr. H. Kynaston shows it to be closely allied to the enstatite-diorites and quartz-norites. (See his notes in Appendix, p. 257.) Another smaller boss, traversed by the Dunning Burn, a little more than a mile above the village, is a coarse-grained crystalline rock and resembles externally the older diabases of the region. A thin slice of this rock examined under the microscope by Mr. W. W. Watts was found to "consist of augite and hypersthene imbedded in and occurring amongst large plagioclase prisms, some iron-ore being also present; the rock is a hyperite." A somewhat similar rock forms a small boss at Corb Bridge, five miles south from Dunning, and is described by Mr. Kynaston as a hyperite or norite. (Appendix, p. 257.)

The large basic dykes form prominent features in the geology of the region. But they are much younger than the Old Red Sand stone, and consequently will be more appropriately considered in a later section of this volume.

Descriptions of the mode of occurrence of the various types of rock which have been enumerated in the foregoing pages will now be given in order to present an intelligible picture of the present condition and original history of the volcanic series of the Lower Old Red Sandstone. For this purpose it will be most convenient to take a series of easily accessible traverses of the Ochil chain, and to show the nature and succession of the rocks that may be seen in each of them.

1. *Traverse of the Ochil Chain from Rumbling Bridge to Dunning.*

First, let us follow a section through the very heart of the hills as exposed along or not far from the road that runs from the Rumbling Bridge to Dunning (Fig. 1). Beginning at the southern end, we find ourselves among the agglomerates that form the lowest visible portion of the whole volcanic series. These rocks lie here on the dome or flattened crest of the great anticlinal fold above referred to. Hence, as they are flat or only gently undulating, they occupy the lower grounds, where they have been laid bare by denudation, in valley after valley, while the lavas that overlie them form the upper parts and cappings of the surrounding hills.

The southern limb of the anticline is here cut off by a large dislocation, whereby the Carboniferous formations are brought down against the rocks of the Ochil Hills. Immediately to the south of this fault the shales, clays, sandstones, and cement-stones of the lowest group of the Carboniferous system are seen in the bed of the River Devon below Nether Dalkeith. On the north side lies the great volcanic series of the Lower Old Red Sandstone. The observer has here excellent facilities for the study of this series, seeing that it has been laid open in the ravine cut in it by the Devon, as well as on many rocky hummocks and occasional quarries on the surrounding ground. Nowhere, however, is the bottom of the vast volcanic pile laid open. The lowest rocks visible are coarse and fine agglomerates and tuffs—

FIG. 1.—Generalised Section across the heart of the Ochil Hills from Dunning on the North to near Saline in the Fife Coal-field on the South.

1. Volcanic agglomerates and tuffs. 2. Andesite and orthophyre lavas. 3. Sandstones and conglomerates (Lower Old Red Sandstone). 4. Intrusive bosses of felsitic rocks. 5. Intrusive boss of hyperite. 6. Upper Old Red Sandstone. 7. Cement-stone group of Lower Carboniferous series. 8. Volcanic zone (tuffs and lavas) in Lower Carboniferous series. 9. Hurlet Limestone (base of Carboniferous Limestone). 10. Dolerite sill. 11. Sandstones, shales, and coals of the Carboniferous Limestone series. 12. Volcanic neck belonging to the Carboniferous Limestone period. *f.* Fault.

thoroughly volcanic materials, derived from the explosion of various andesitic lavas. The blocks in them vary up to three feet or more in diameter, and are angular, subangular, or roughly rounded. The matrix in which they lie is a finer detritus of the same materials. For the most part the agglomerates are unstratified. But here and there more or less distinct bedding may be observed in them, such as might have resulted from a partial rearrangement of the ejected stones and dust by the movement of the water into which they fell. A good section of the unstratified condition of the agglomerate may be seen on the side of the road immediately to the south of the Rumbling Bridge Station. An example of the indefinite reassortment of the debris into layers may be found in an old quarry at the farm of Craigend, on the inlier of the Monk's Grave, a little farther east. The rude bedding of the rock is seen in the upper part of the quarry, which is further interesting from the presence of numerous angular fragments of a somewhat decayed pink orthophyric rock with beautiful flow-structure.

It will be understood that the coarse agglomerates now described indicate the fragmental discharges of one or more volcanic vents in this neighbourhood. The thickness of the accumulation cannot be ascertained owing to the concealment of its bottom, but must amount to at least several hundred feet. On this foundation of consolidated breccias and tuffs the whole vast volcanic pile of the Ochils rests.

The same mass of agglomerate and tuff may be seen at intervals

in the bed of the Devon above the Crook. At Fossaway it passes under the group of lavas which extends northwards through Lendrick Hill (1496 feet), and sweeps thence over the surrounding hills to the north, east, and west. The road runs upon the agglomerates as far north as Whiteriggs, four miles and a half above the Crook of Devon, and the same basement rocks may be traced for many miles westward along the course of the River Devon and its tributary valleys, forming everywhere the lowest volcanic platform. Good sections of them may be examined in the streams which descend from the Lendrick ridge between Fossaway and Whiteriggs, and in the channel of the Devon itself. Occasionally they may be observed to include a thin lava-bed or a sill, while intrusive bosses and dykes may also be noticed in them. At the foot of the Glendey Burn, where our road turns northward from the Devon valley, a compact purplish andesite has invaded the agglomerate, and has sent numerous veins and threads into it and indurated it along the contact. The last section of this great sheet of agglomerate exposed in the valley of the Glendey Burn will be found in a small streamlet which, descending from the higher slopes of Lendrick Hill, shows a coarse agglomerate enclosing angular fragments and blocks of andesite in a dirty chocolate-brown matrix, some of the included masses being several feet in diameter. Higher up this brook, the agglomerate is seen to be pierced by a number of veins or sills, by which it has been much indurated. About 630 yards above the mouth of the brook, and at a height of 300 feet above the bottom of the valley, the lavas supervene. Hence, a thickness of at least three hundred feet of coarse pyroclastic material can here be studied. The upper limit of the agglomerate is well defined by the bottom of the overlying lavas, which, as the whole volcanic series continues so flat, can be followed as a nearly level line, winding along the hill slopes on either side of the Glendey valley and far up the vale of the Devon.

These lavas, about 400 feet thick in Lendrick Hill, pass under a sheet of coarse tuff or agglomerate, of which only a small outlier is left as a cake capping the summit of the ridge. They are further exposed on the roadside above Whiteriggs, where they consist of dark purplish amygdaloidal andesites of the usual type.

They are succeeded by felsite-like orthophyres which display well-marked flow-structure and are often brecciated. The occurrence of such acid rocks, in alternation with andesites and even more basic lavas, has already been referred to as having long been noticed in the corresponding volcanic mass of the Pentland Hills. The occurrence of fragments of these rocks in the conglomerates and sandstones proves that they belong to the volcanic series, but it is sometimes difficult to decide whether the sheets which the orthophyres form should be regarded as interstratified lavas or as subsequently intruded sills. The broken-up flow-structure sometimes closely simulates true pyroclastic breccia, and it is quite possible that some of it may actually be due to the accumula-

tion of ejected fragments. But there seems to be no doubt that in other cases it is a brecciation that was produced during the flow of the pasty rock, when the parts that had become devitrified and solid were disrupted and carried along by the still uncongealed portions. These rocks are typically developed at Craig Rossie, near Auchterarder, and are further referred to on p. 23.

Upon the hill-slopes on the west side of the valley, above Whiteriggs, a band of tuff is exposed in several watercourses, lying among the dark andesites. What appears to be the same band is traceable on the east side of the valley round the side of Myrehaugh Hill. At the Lamb Linn, a waterfall on the South Queich above Myrehaugh, dark fine-grained andesite appears, together with some indurated coarse agglomerate. At another small waterfall a little further up the stream the top of another andesite sheet shows a somewhat slaggy matrix, and has included large blocks of different andesites. Three hundred yards from the Lamb Linn a pink felsitic dyke rises vertically through a purple andesite of normal type. It crosses the stream and appears to be the same as one which may be seen slanting across Glenross Burn on the west side of the ridge of Mellock Hill. The rock of this dyke is somewhat crystalline and possesses a well-marked banded flow-structure, the striping running parallel to the vertical walls. This structure sometimes exhibits a wavy wriggling round cores of a pseudo-spheroidal nature. Alternations of pink and pale purplish breccias, or brecciated orthophyres and andesites, form the next parts of the volcanic series on either side of the valley. These rocks, as already mentioned, present many points of resemblance to the pale rhyolite-like orthophyres and tuffs of the Pentland and Peeblesshire Old Red Sandstone volcanic series. In some parts they are fissile and laminated, but so decomposed that it is often hardly possible to determine whether their internal arrangement should be regarded as the flow-structure of lavas or as the stratification of fine tuffs.

The watershed is reached at a point on the road a little more than half a mile above Littlerig, at a height of 1000 feet above the sea, but there is no perceptible ridge. We pass insensibly across the divide and find ourselves in the valley of the South Queich Water, the drainage of which flows south-eastwards into Loch Leven and thence by the River Leven into the Firth of Forth. North of the watershed the brooks converge into the Water of May, which turns northward into the River Earn and thus drains into the Firth of Tay.

As we continue the traverse we begin to observe that not only have we passed over the watershed, but we have also imperceptibly crossed the axis of the anticlinal fold, and that the traverse leads us somewhat more rapidly through an ascending section in the volcanic series. At Corb Bridge the stream flows over a band of rather coarse agglomerate and tuff which, further down the valley, includes numerous felsitic dykes and sheets, while immediately above the bridge it is pierced by the small boss of coarsely

crystalline "greenstone" above referred to. The rock forming most of this boss has been examined microscopically by Mr. H. Kynaston, who remarks that it shows a crystalline doleritic texture, and is composed of plagioclase and enstatite, with a little interstitial quartz and unstriped felspar. As already stated, it may be called Hyperite or Norite. It may represent the deep-seated portions of the enstatite-andesites. Beyond this intrusion a tolerably continuous section of higher volcanic rocks includes reddish, pinkish, and yellowish decomposed orthophyres, with vesicular andesites, bands of agglomerate and tuff, and occasional veins of felsitic and mica-bearing rocks. One of these dykes which crops out along the bank on the south side of the road, about 400 yards east from the Bridge, has been examined by Mr. Kynaston, whose description of it will be found in the Appendix. On the roadside a quarter of a mile north of Greenhill, a coarse agglomerate may be seen with blocks of the normal type of andesite 18 inches in diameter. The rocks which continue northwards by Tongue Faulds, Ferny Braes, and Greenhill are then traversed by a fault which depresses them on the eastern side. A thick intercalation of tuffs thereafter makes its appearance and continues to show itself in numerous exposures as far as Blaeberry, where it passes under some vesicular andesites. These lavas traced northwards are soon found to be overlain by a thick accumulation of tuffs and breccias which, with occasional intercalations of lava-sheets, occupy most of the rest of the valley down to Dunning.

Two dolerite dykes cross the line of section on the north and south sides of Cockersfauld. These rocks, obviously of far later date than those with which we are now dealing, probably belong to the great Tertiary series, which plays so important a part in the geological structure of Scotland. They will be described in a later part of this volume (p. 172).

In pursuing our line of traverse we come upon several of the vesicular or amygdaloidal andesites just referred to as interstratified among the tuffs to the north of Cockersfauld. One of these is well exposed in the Dunning Burn immediately below Shorter Bridge; another and thinner sheet may be seen on the upper side of the bridge. The rocks have now a decided inclination northwards or down-stream, and the angle of inclination gradually increases, so that we enter with increasing rapidity into higher portions of the series. This northward dip can be detected even from a distance by the slope of the escarpments, as is well displayed on the hill-side to the east of the Dunning Burn, immediately to the north of the Balquhandy Burn.

A little below Quilts the mass of hyperite, to which reference has already been made, pierces the lavas and tuffs. It forms a boss which is traversed for a breadth of 700 feet by the stream. On its eastern side a narrow dyke of "greenstone," which may be an off-shoot from it, traverses a characteristic example of the pyroclastic materials of this group of rocks—a reddish and greenish tuff, consisting of angular, subangular, and rounded lapilli and larger

pieces of different lavas imbedded in a dull granular paste. This rock has a more or less distinct bedding, its strata dipping towards the north-west at about 8°. Further down, below the Pitincailow dolerite-dyke, the tuff is coarser, contains lumps of vesicular andesite, and has scattered felspar crystals in its matrix. Similar large and small blocks of slaggy andesite may be seen in the tuff that overlies a sheet of andesite below Pitincailow.

A fine section of the highest members of the volcanic series in this part of the district has been laid open in the Pitcairns Glen by the erosion of the Dunning Burn. Above the thick accumulation of tuff that extends northward beyond Pitincailow, a mass of dark andesite supervenes which can be followed for some 400 yards down the glen. Its upper portion presents the slaggy amygdaloidal structure characteristic of the surface of a true lava-flow. It passes below an interesting group of alternations of volcanic tuff with ordinary sandy and gravelly sediment. The sandstones and conglomerates, though largely composed of non-volcanic detritus which was transported from some source outside of the volcanic area, includes much igneous material. Thin bands of tuff alternate with the red sandstones and conglomerates, the whole group being inclined towards the north-west at from 10° to 15°. Some of the tuffs are still tolerably coarse, for they enclose stones measuring a foot in diameter.

By degrees the volcanic materials diminish in quantity and give place to a group of red, grey, and brown flagstones and shales forming the base of the great overlying Lower Old Red Sandstone of Strath Earn. But even when the deposition of ordinary sediment had set in and had begun to bury the huge pile of volcanic material, the eruptions had not entirely ceased. We have evidence of this continuance of subterranean activity in two separate sheets of andesite intercalated among the sandstones and shales close to Dunning. One of these is crossed by the Dunning Burn immediately above Newton of Pitcairns; the other and larger mass is the rock of Dunning quarry, a quarter of a mile west from the village. That some part of the volcanic bank remained long above water may be inferred from the abundance of rolled fragments from its lava imbedded in the sandstones and conglomerates of the overlying sedimentary series.

Reference has been made in the foregoing pages to Craig Rossie, near Auchterarder, and as the remarkable rocks of that hill and its neighbourhood stretch nearly as far as Dunning more special reference to them seems to be required here. They appear on the Geological Survey maps as tuffs and volcanic breccias, to which they have in many respects a most deceptive resemblance. Recent renewed examination of them, however, has proved that they are not clastic rocks, but true lavas with admirably perfect flow-structure. It is the singular perfection of this structure which has led to their being regarded as stratified masses.

Craig Rossie is the central and highest eminence in a chain of hills composed of the type of rock now referred to. The mass

reposes upon the ordinary dark slaggy andesites, and dips gently north-westwards like the rest of the volcanic series. The rock is pinkish-grey, weathering almost white and then passing into a kind of "claystone." On a fresh fracture the texture is felsitic or horny. Porphyritic felspars are everywhere abundant, and small plates of mica are sometimes numerous. But the distinguishing characteristic of the rock is its flow-structure, which on fresh faces appears in cross-section as parallel inconstant streaky lines, sometimes wavy and occasionally overfolded. The rock has evidently been tolerably viscous while flowing. There is a kind of "crag and tail" arrangement in the lee of the larger phenocrysts, like the wisps of crushed material behind the larger fragments of the crushed pegmatites in Sutherland and Ross. And this arrangement gives rise to little confluent ridges and knobs on weathered surfaces. Here and there the laminæ have been broken up after consolidation, and the fragments have been enveloped in a matrix of the still moving material, so as to give rise to a flow-breccia.

Occasionally pieces of the dark andesite are enclosed in the rock. There occur also ovoid or ellipsoidal inclusions which are mainly composed of a minute quartz aggregate or mosaic, and are doubtless of secondary origin. These ellipses remind one of the structures of some nodular silicified felsites.

So parallel and defined are the lines of flow that they give the rock a thoroughly flaggy structure, so that it could be split into large thin slabs. No one looking at it from a little distance would be likely to take it for anything but a truly bedded rock. Closer examination, however, would show him that now and then the apparent stratification makes a great curve upward or downward after the manner of rhyolites and obsidians.

A microscopic examination of this rock by Mr. H. Kynaston shows it to possess a groundmass of microcrystalline quartz and felspar and felsitic material with numerous small idiomorphic felspars. The larger porphyritic felspars include probably orthoclase and an acid plagioclase. A small proportion of rounded quartz-grains is present, together with more numerous flakes of biotite. (See Appendix, p. 254.)

That this interesting rock is not an intrusive mass, but a true lava which was poured out at the surface, is convincingly shown by a section in the line of railway near Pairnie, a little to the north of Craig Rossie. At the east end of the cutting the Craig Rossie rock may be seen with its usual features. It there passes under a conglomerate or agglomerate made up of its fragments which are imbedded in a matrix of fine green and red sand. The stones are angular and subangular, sometimes somewhat rounded, and have been thrown down promiscuously, large and small, with no bedded arrangement and not infrequently standing on end. The appearance of this deposit suggests some process such as that of volcanic explosion, whereby stones of all sizes, up to two feet in diameter, were thrown down upon a water-bottom where fine sandy silt was accumulating at the time, and where the silt eventually filled up

the interstices between the loose blocks. The sandy constituent increases in quantity, and the stones diminish in number and size, as the deposit is traced upward, though an occasional band of breccia may still be met with. But eventually the strata pass up into the ordinary red sandstones that underlie the plains of Strath Earn.

The felsitic rock of Craig Rossie is thus the latest of the volcanic outpourings of that part of the Ochil chain. It furnishes a fresh example of the law that in a prolonged volcanic period the last emitted lavas tend to assume a more acid type than those with which the first eruptions began.

The great plain of Old Red Sandstone between the chain of the Ochil Hills and the flanks of the Highlands lies beyond our present district. It may be mentioned, however, that the red sandstones of this region which overlie the Ochil volcanic series are proved to belong to the Lower Old Red Sandstone by the discovery in them of specimens of *Pteraspis* and other typical fishes near Bridge of Allan. Again, on the eastern side, from beneath the volcanic pile in the Carse of Gowrie, other organic remains have been obtained belonging to an older part of the same division of the geological record.

2. *Traverse of the Ochil Chain along Glen Farg.*

A second traverse of the Ochil chain, about ten miles further to the north-east along the line of Glen Farg, will be found to differ in most respects from that which has just been described (Fig. 2). The ground is much lower, the hills on either side ranging from 700 to 900 feet. The area lies on the south-eastern side of the anticline, so that, the rocks being inclined in a south-easterly direction, successively lower members of the volcanic series are met with as we cross the chain from south to north. Again, the vast underlying mass of agglomerates and tuffs is now deeply buried under higher portions of the series, which here consists almost entirely of lavas. It is obvious that in moving towards the north-east we leave behind us the chief centre of eruption in this part of the Ochil chain. The ashes do not seem to have been discharged over such long distances as were reached by many of the outflows of lava.

Following the plan of taking the older portions of each series of rocks first, we must reverse the direction pursued in the previous traverse, and begin at the north side of the hills. As the valley of Glen Farg has offered a convenient route for both the Great North Road and for the line of railway by way of the Forth Bridge to Perth, numerous instructive sections are to be met with on the sides of the valley, in the bed of the stream, along the high road, and in the railway cuttings. Starting on the Carse-land of the lower part of Strath Earn (Sheet 48), and looking eastwards down the line of the Firth of Tay, we can follow with the eye the line of axis of the great anticlinal arch already referred to. On the left, or north (Perthshire) side, the escarpments along the steep hillsides

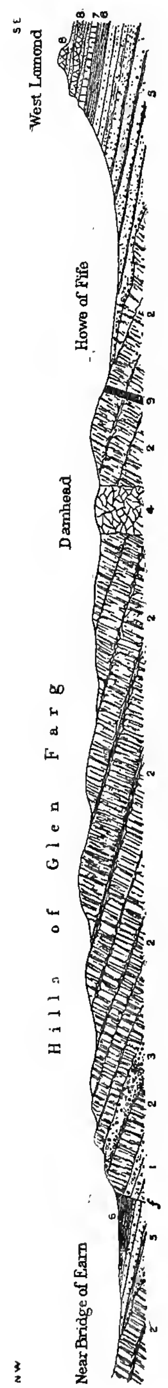


Fig. 2.—Diagram-section across the Ochil Chain from near Bridge of Earn to the top of the West Lomond.
1. Volcanic agglomerates and tuffs. 2. Andesite lavas. 3. Volcanic conglomerates. 4. Boss of quartz-diorite. 5. Upper Old Red Sandstone. 6. Cement-stone group. 7. Hurlet Limestone. 8. Sills of dolerite injected into the Carboniferous Limestone series. 9. East and West doleritic dyke, possibly of Tertiary age. *f*. Fault.

face to the south-east, while the dip slopes, which show the inclination of the rocks, are directed to the opposite quarter. The southern, or Fife, side displays an arrangement exactly the reverse; we can mark that the dip of the rocks is there towards the south-east.

We first cross the platform of the 50-feet raised beach, which, though here more than two miles broad, rapidly contracts above Bridge of Earn to not more than half a mile. This marine platform forms a broad fertile plain, through which the Earn meanders until it joins the Tay four miles below Bridge of Earn. A higher terrace, belonging to the so-called 100-feet beach, may be traced as it winds along the slopes between the plain of the lower beach and the steeper rise of ground immediately to the south. Between the edge of this terrace and the foot of the hills occasional exposures of rock show that the Upper Old Red Sandstone fills the bottom of this part of Strath Earn. These strata at Quarry Hall, west of Bridge of Earn, lie unconformably upon the lavas of the older division of the system. The exposure is unfortunately now filled up, but numerous blocks of the dull purplish-red sandstone may be seen enclosing pieces of andesite and also fragments of the Craig Rossie type of rock. The same strata cross the Tay and underlie the Carse of Gowrie, where, at Clashbennie, they long ago furnished the original type specimen of the characteristic Upper Old Red Sandstone fish, *Holoptychius nobilissimus*. That we are here dealing with the highest portion of the Old Red Sandstone is shown by the occurrence of a small outlier of the basement beds of the Carboniferous system which has survived at East Dron. These strata consist of red and greenish shales and marls, white and red sandstones, and fine conglomerate, evidently belonging to the "Cement-stone group," to be afterwards described. This identification of their stratigraphical position is confirmed by the discovery in them of remains of Lower Carboniferous species of plants,

shells and fish. The survival of such a small patch of strata raises some interesting questions. It indicates, for reasons to be more fully given a few sentences further on, that part at least of the Carboniferous system extended across the Ochils, and spread northward into the region beyond. How far this system ever stretched over the area of the Highlands remains for future determination. There can be no doubt that Carboniferous strata covered some part of Argyllshire, as is shown by the survival of portions of them at Campbeltown, Pass of Brander, and Sound of Mull.

The Upper Old Red Sandstone and Carboniferous formations of Strath Earn have been dropped into their present position by two main faults which run approximately parallel in a north-easterly direction along the centre of the anticline. It is as if the crown of an arch had given way and sunk down. The line of the two fractures nearly coincides with the abrupt rise of ground on either side above the alluvial plain. It will be seen from the map (Sheet 48) that a portion of the volcanic series has also been dropped between the two faults in the middle of the valley south of Forgandenny. The extent of displacement in these dislocations may amount to several thousand feet, for the younger formations are brought down against the lowest parts of the Lower Old Red Sandstone series along the crest of the great anticline. It can hardly be more precisely determined without fuller information as to the extent of the unconformability of the younger formations on the Lower Old Red Sandstone. If in imagination we attempt to reconstruct the original arrangement of the strata, we perceive that the Carboniferous shales of Dron, on any view of the unconformability, must at first have lain many hundred feet higher, and in that position would be prolonged across the site of the Ochils. If, further, we suppose, as is highly probable, that these shales were followed continuously by the rest of the Carboniferous system, we realise that the Ochil chain may well have been actually buried under a deep overlying cover of younger Palæozoic sediments.

Let us now cross the line of the great fault immediately to the south of Aberargie, on the edge of the alluvial plain of lower Strath Earn. The actual fault itself cannot be seen owing to the spread of superficial deposits. But the rocks on the two sides can be traced to within about 150 yards of each other. At the lodge of Ayton House, red sandstones and conglomerates are exposed in the brook, while at the mill immediately to the south, the dark andesites of the volcanic series make their appearance. The line of fault must pass through the alluvial haugh between these two points.

Though the base of the volcanic rocks is not seen here, owing to the effects of the fault, there can be little doubt that the andesites lie not far above the bottom of the series. About four miles to the north-east, sandstones and conglomerates are found to rise from underneath the lavas, and to extend for some ten miles along the south-side of the Firth of Tay. These strata

present the ordinary characters of the sedimentary portion of the Lower Old Red Sandstone of this region. But they were not entirely deposited before the beginning of the volcanic eruptions, for on the shore about a mile south-west from Balmerino they include some bands of andesite.

It will be observed that there is here no representative of the thick mass of agglomerates and tuffs which forms the foundation of the volcanic pile of the Ochil chain further to the west, as above described. The lavas come immediately above the lower sandstone series. But they include several bands of tuff and volcanic conglomerate. Of these the lowest are well seen at the foot of Abernethy Glen, where, though they consist mainly of conglomeratic material derived from the lavas, they include also layers of greenish felspathic sandstone, which show a gentle inclination towards the south-east. A similar volcanic conglomerate is intercalated among the lavas.

At the mouth of Glen Farg, immediately to the south of Ayton House, the bottom of the gorge is occupied by dark purplish finely porphyritic andesites, which dip gently into the hills and extend southwards as far as the 7th milestone from Perth. The upper surface of the highest sheet is highly vesicular and slaggy, and passes under a coarse agglomerate of angular and subangular fragments of andesite like the lavas underneath, embedded in a granular matrix of the same material. This fragmental band has a thickness of about 200 feet. It forms the crags on the west front of Trapmore Hill, in the grounds of Ayton House, and is well seen also at the north-western mouth of the railway tunnel near Kilnockiebank. At its upper limit in the bottom of the glen, it is pierced by one of the smaller intrusive bosses, consisting of a fine-grained purplish-grey porphyrite, in which the minute porphyritic felspars have a general orientation parallel to the faces of a set of curved divisional planes whereby the rock is split into thin slabs. (See Mr. Kynaston's description of this rock in the Appendix.) Thereafter the lava-sheets set in with a copious development, and continue throughout the rest of the traverse. They consist of dark-brown, purple, or blue compact andesites, often abundantly vesicular or amygdaloidal, and presenting the characteristic slaggy structure of true lavas. Some of these sheets are beautifully porphyritic, from the presence of large flat tabular plagioclase crystals. An occasional bed may be noticed which weathers spheroidally, is more solid and massive than the ordinary andesites, and on a fresh fracture shows abundant hæmatitic pseudomorphs, after a pyroxene or olivine, and others of a black mica. The amygdaloidal kernels consist of various minerals of infiltration, particularly calcite, agate, quartz, and zeolites. Among the minerals for which these andesites have long been famous, the following may here be cited:—Calcite, quartz, chalcedony, prehnite, laumontite, analcime, natrolite, saponite, celadonite. Besides these amygdaloidal minerals, the andesites have yielded a number of other species in veins or nests or diffused

through the body of the rock. These include native copper, chalcocite, pyrite, fluor-spar, cuprite, hæmatite, iserine, limonite, psilomelane (in dendritic form), malachite, datolite, chrysocolla, and hydro-carbon compounds. The distinctive mineral components of these rocks are plagioclase (commonly labradorite), enstatite, augite, olivine, and magnetite.

The andesite lavas usually succeed each other without the intercalation of tuff or any stratified deposit. But the successive flows can easily be distinguished by their peculiarly slaggy upper and under surfaces. Some admirable fresh examples of this structure may be seen in the railway and in the new cuttings required by the deviation of the high road. The absence of intercalated sedimentary layers probably accounts for the absence of the ramifying veins of sandstone, which are so characteristic of the lavas of the same period in other parts of Scotland, and even in the prolongation of the Ochil chain into the east of Fife at Tayport. Possibly the lavas in the Glen Farg district followed each other so rapidly that they allowed insufficient time for the deposition of sediment between them.

Immediately to the south of where the road crosses the Farg for the last time, an interesting section may be seen by the side of the railway, where an andesite sill, similar to the basic pyroxene-andesites above and below it, has thrust itself between them. It is five feet thick on the level of the rails, but rapidly thins away northward. At its contact with the contiguous andesite, it shows the fine-grained edge induced by more rapid cooling, and this marginal portion is finely cellular, the minute vesicles being drawn out into tube-like shapes parallel to the surface of contact. The body of the rock is crowded with porphyritic felspars, which have arranged themselves parallel with the planes of the sill. (For petrographical descriptions of these rocks by Mr. Kynaston, see Appendix.)

Beyond the southern end of the glen two dolerite dykes belonging to the Tertiary series, to be afterwards more fully considered, rise through the volcanic series. One of these crosses the line of traverse immediately south of Damhead, and has been quarried away so as to leave the vertical walls of the fissure up which the molten material ascended. The second and more important example occurs a little further on at Thievesmill, near the farm of Carmore.

In this neighbourhood lies the large boss already noticed as piercing the volcanic series a little to the west of Duncrevie. At the south-western edge of the mass the rock encloses angular pieces of amygdaloidal andesite.

Immediately to the south of the Thievesmill dyke, which has been cut through in the railway, we emerge from the volcanic series and enter the area of the Upper Old Red Sandstone of the Kinross-shire plain and the Howe of Fife. Although the actual junction of the two formations is not seen, there can be no doubt that here, as elsewhere, it is formed by a marked unconformability.

All the vast mass of red sandstones and conglomerates which, on the other side of the hills, overlies the volcanic rocks in Strath Allan and Strath Earn, as well as in Strath More, is here completely overspread and buried by the younger formation.

3. *Traverse of the Ochil Chain between Newburgh and Auchtermuchty.*

The third traverse, which may be made for the purpose of illustrating the nature and arrangement of the rocks that form the Lower Old Red Sandstone of this district, runs across the Ochil range from Newburgh to Auchtermuchty (Fig. 3). Along the shore of the Firth of Tay a strip of red sandstones and conglomerates emerges from underneath the volcanic pile, but is mostly concealed under the raised beaches. Immediately behind Newburgh the lavas make their appearance, and form a line of bold escarpments, which face the firth for many miles. Nowhere throughout the district does the inner anatomy of the ground reveal itself more clearly at the surface than along the steep slopes between Newburgh and Glen Farg. Each successive sheet of the great volcanic mass shows its position by a rocky rib or grassy depression, and these features, running parallel to each other, retire into each recess that has been worn out of the declivities. The lowest lavas at Newburgh are dull green slaggy and amygdaloidal andesites of common types. Immediately to the south of the railway at the east end of the town they are followed by an intercalation about 30 feet thick of volcanic conglomerate and sandstone. The lowest sandstone lies directly upon the slaggy top of an andesite, and fits into its inequalities so closely that at first the line of demarcation between the two rocks is not quite apparent. These sedimentary materials have been derived almost entirely from the destruction of volcanic rocks, partly by ordinary aqueous erosion, but partly also, perhaps, by volcanic explosion. The fine andesitic material of the sandstones may be largely of the nature of ash or tuff. Above these strata lies a remarkable rock which forms a succession of crags along the front of the steep ground behind Newburgh. It is conspicuous from a distance by its massive thickness, its precipitous cliffs, and the rich yellow tint it assumes on weathering —features which mark it off in contrast with those of the ordinary andesites. On examination it is found to be a fine-grained grey rock like some of those which have been observed forming intrusive bosses. It has a strongly - developed platy structure, the plates or flags being highly inclined or vertical. It is not vesicular or amygdaloidal, but retains the same persistent close texture and platy arrangement. It resembles the intrusive porphyrite above described as exposed in the quarry near the foot of Glen Farg. A thin section of the rock examined under the microscope gave the characters enumerated at p. 256 of the Appendix.

That this rock is a great sill and not one of the true surface lavas might be inferred from its texture, its uniformity, and its mass. But this inference can, fortunately, be confirmed by nearly conclusive

FIG. 3.—Diagram-section across the Ochil Chain from Newburgh to Auchtermuchty.
1. Red sandstones and conglomerates. 2. Andesitic lavas. 3. Volcanic conglomerates and tuffs. 4. Intrusive sill. 5. Upper Old Red Sandstone. 6. Dolerite dyke, probably of Tertiary age.

proofs. The rock forms the commanding eminence of Clatchard Hill, crowned by an ancient fort, and it presents on the north side a high cliff which descends to the railway. The top of the hill is 390 feet above the sea, and the base of the porphyrite 160 feet, so that the rock must be more than 230 feet thick, for its top is not seen. Few of the individual sheets of andesitic lava attain a fourth or fifth part of that thickness. Where it rests upon the zone of conglomerate and sandstone, above referred to, the intrusive mass sends veins into it, and in at least one place has invaded the sandstones by sending a sill between their strata. There can thus be little doubt that this massive sheet is intrusive. It forms the most important sill that has yet been detected in the Ochil chain.

The ordinary andesites resume their place further south with their familiar characters. They include an occasional intercalation of sandstone or of conglomerate mainly composed of volcanic detritus. The most important of these, and that on account of which this traverse is mainly taken, is a great bank of interposed conglomerate, which is about nine miles in length, for it stretches from above Strathmiglo to beyond Monimail. It attains a maximum thickness of probably not less than 1700 feet. It includes some interstratified sheets of andesite, which are most numerous in its south-western part, where they thicken out and join together. Another group of lavas, intercalated in its lower portion, dies out towards the south-west, but increases rapidly in the opposite direction, till the several sheets conjoin to the exclusion of the conglomerate. It would thus appear that during the piling up of this bank of fragmental material, one set of lava-streams reached it from the north-east, while another flowed up to it from the south-west. The conglomerate rapidly dies out among the lavas along its line of strike, both towards north-east and south-west. It is traversed throughout its length by the Tertiary dyke last mentioned.

This remarkable accumulation of fragmentary material may be conveniently

examined by the side of the road leading north from the village of Auchtermuchty, and also in the Glassert Den, through which flows the Beggar's Burn, a little further north. Its upper parts consist of an andesitic agglomerate, which appears to have originated more from volcanic explosions than from the denudation of exposed lava. Comparatively few of the stones are rounded, most of them being subangular or angular. It is a dull dirty-green unstratified rock, of which the matrix is a granular paste of andesitic detritus.

In the Glassert Den good sections of lower parts of the deposit show it to contain much more distinct evidence of water-action and to be mainly a conglomerate of volcanic materials, though including coarse unstratified parts that can only be called agglomerate. The component blocks, sometimes measuring two feet in diameter, consist of many varieties of the eruptive rocks of the hills. Slaggy andesites and orthophyric rocks of different types may be observed, together with pieces of fine-grained tuff. These materials, always thoroughly volcanic in origin, may have been partly derived from explosions, but they obviously underwent considerable abrasion and re-arrangement under water. That the eruptions were subaqueous is indicated by the rounded and smoothed or water-worn forms of many of the stones, by their arrangement on their flat sides, by the stratification of the conglomerate, and by its intercalation with and passage into layers of fine and coarse felspathic pebbly sandstone. Such stratified zones in the body of the rock may mark intervals of comparative quiescence in the volcanic discharges, when the loose detritus already thrown out over the floor of the lake was in some measure re-assorted by the water. That there may have been some emergent parts of the volcano or volcanic bank exposed to wave-action seems to be intimated by the roundness of many of the stones, especially in those parts of the deposit where stratification is best developed, in contrast to the preponderance of angular and subangular fragments in the more tumultuous portions. The loose slaggy surfaces of the lavas might furnish some of the shingle, though most of it may rather have been derived from the washing down of the sides of one or more volcanic cones built up of ashes and stones.

While no part of this intercalated mass of fragmentary material can be regarded as certainly marking the actual vent from which the stones were discharged, the site of the eruptive orifice can hardly be far off. Possibly it may lie a little to the south on the area now covered by the Upper Old Red Sandstone. The conglomerate passes underneath an upper series of andesites on which the village of Auchtermuchty has been built, while immediately to the south lies the plain of the Upper Old Red Sandstone, the junction between the two formations being here buried under drift over which is spread the alluvium of the vanished Rossie Loch.

CHAPTER IV.

Upper Old Red Sandstone.

Reference has already been made to the occurrence of the Upper Old Red Sandstone on the north side of the Ochil chain, where it has been let down between two parallel faults along the centre of a great anticlinal fold. On the south side of the chain the same formation occupies an extensive tract of country, which includes the wide plain of Kinross and the long valley of Strath Eden known as the Howe of Fife.

Though this subdivision of the system must obviously lie unconformably on the Lower Old Red Sandstone and its volcanic pile, no single section in the present district can at present be adduced in proof of this relation, for the junctions of the formation are buried under drift, and the section formerly visible to the west of Bridge of Earn is now filled up, as has been already mentioned (p. 26). But it is evident, from the large part of the lower division which is concealed along the south side of the Ochil chain, that the upper division overlaps it and spreads across its denuded outcrops.

A nearly complete section of the Upper Old Red Sandstone, as developed in this district, is supplied by the Glen Burn, which rises on the West Lomond Hill and flows across the strike of the strata into the Eden. If we take the line of that stream from the base of the Carboniferous escarpment of the Lomond Hills to the edge of the volcanic series near Edentown and allow a south-easterly dip of 5°, a thickness of rather more than 2000 feet would be obtained. But the angle of inclination sometimes falls to no more than 3°, and there may be some slight undulations and small faults in those parts of the ground where the strata are concealed for a brief space under drift. We shall probably not over-state the thickness if we assume it to be 1500 feet. It must be remembered, however, that the true base of the formation is not seen here, and that the visible thickness of strata may not represent the whole of the Upper Old Red Sandstone.

This mass of strata consists of sandstones, marls, and conglomerates, generally of a dark brick-red colour, but with intercalations of yellow, green, and white tints. At their top immediately below the cornstone, which is taken as a convenient line of division between the top of the Upper Old Red Sandstone and the base of the Carboniferous system, they are overlain by a zone of white and yellow sandstones.

The age of these sandstones and their associated strata in this district is made clear by the evidence of fossils. Not many miles

to the east lies the famous locality, Dura Den, whence so large a number of well-preserved Upper Old Red Sandstone ichthyolites has been obtained. Some of the same characteristic genera and species of fossil fishes have been detected at many places within the present district all along the Howe of Fife from Pitlessie, near Cupar, to the plains of Kinross-shire. So that there can be no doubt that the Upper Old Red Sandstone of Dura Den is continued westward between the base of the Lomond range and the foot of the Ochils. Scales of *Holoptychius* have been found, among other localities, at Easter Cash, near Strathmiglo, at various horizons in the Glen Burn, in the quarry at Easter Gospetry, and in the Butterwell Quarry between Wester Gospetry and Moors of Kinnesswood. Scales of *Bothriolepis* have been obtained from a quarry at Balgeddie, near Kinnesswood. Traces of fish have also been detected in the zone of white and yellow sandstone above referred to as lying immediately below the cornstone.

While occasional sections of the strata may be seen in the brooks that traverse the plain of Kinross, the best and most continuous exposures will be found along the sides of the Lomond, Bishop, and Benarty hills, and more especially in the water-courses by which these slopes have been channelled. The best section in the district, and one of the most instructive in Scotland for showing the general characters of the Upper Old Red Sandstone and its relations to the overlying Carboniferous system, will be found in the course of the Glen Burn just referred to. Issuing from the hollow between the West Lomond and Bishop's Hill this stream has cut a succession of picturesque little ravines through different portions of the strata. From its junction with the Eden near Burnside it has laid open an almost continuous section up to its source. The slopes which it traverses are only thinly covered with drift. The boulder-clay, indeed, now exists here in mere scattered patches, though abundant blocks of Highland rocks, dispersed over the surface of the ground, show that it may once have been deeper and more continuous.

Well-bedded red, grey, purple, and white sandstones, with thin partings of red shale or marl, may be seen for nearly two miles up the Glen Burn. These strata are often flaggy or false-bedded, and many of them are crowded with " galls " or flat pellets of red or purple clay. Some of the beds of this character contain plentiful fragments of *Holoptychius,* which may be readily detected by their white or yellowish colour on the dark ground of the stone. A good locality for searching for ichthyolites will be found at the upper end of the Gospetry fir-wood, above the road that passes by Moors of Kinnesswood and Lappiemoss. A thin band of yellowish sandstone, well charged with clay-galls and containing fragmentary fish-remains, crops out at the foot of the scar on the left bank. A hundred yards further up, similar remains occur in a band of red sandstone at the bottom of the low cliff.

The sandstones become more massive and false-bedded as they ascend in the series, till at a point in the stream a little more than

a mile south-east from Easter Gospetry they are succeeded by the thick zone of soft white and yellow sandstones already mentioned. These differ considerably from the strata below them, not merely in colour, but in texture, composition, and structure. They are, as a whole, coarse in their material, which consists of well-rounded grains of quartz, not infrequently blue, and of rolled grains of felspar. The coarser layers show well the composition of the sediment, which must have been derived from the decay of rocks wherein water-clear and also blue hyaline quartz, as well as white and pink felspar, abounded. So felspathic and decayed are some bands of these sandstones that, when a handful of their substance is thrown into water, a white cloud of clay particles immediately appears. A distinctive feature of this group of strata is to be found in their remarkable false bedding. One bed may be seen with its current lamination inclined towards north-west at 35°. This lamination terminates upward along a sharply-defined plain forming the bottom of another bed in which the layers dip southward at 3°. These, again, are truncated in the same sharp way by another bed in which the layers dip northward at 5°, while above it lies a band in which the laminæ are inclined in the same direction at 15°. These structures furnish a suggestive picture of the shifting water-currents by which this group of pale sandstones was accumulated.

These white and yellow sandstones appear to form the uppermost zone of the "Dura Den beds" of the East of Fife. Though they have not yielded here the same remarkable assemblage of fishes as that for which Dura Den itself has long been celebrated, they contain fish-remains, as was recently ascertained by Mr. B. N. Peach. They perhaps only need to be quarried and laid open in a fresh and unweathered condition to supply a similar series of ichthyolites.

These sandstones continue for about 900 yards up the stream, and in this space almost every one of their beds is exposed in natural section, either in the bed of the water-course or in weathered scarps and cliffs on either side. They are probably from 200 to 250 feet thick. At the head of a narrow gorge which the stream has cut in them, and which ends at a waterfall, they contain sandy nodular cornstone bands, of which as many as eight may be counted in a thickness of 20 feet of soft white sandstone. Some of the sandstone beds are also crowded with small concretions of sand grains held together by a calcareous cement, and weathering out in small pea-like aggregates. There can be little doubt that this zone represents the cornstone which has been so generally found to mark the upper limit of the Upper Old Red Sandstone. It is succeeded by a representative of the Cement-stone group at the base of the Carboniferous system, to be afterwards described.

One of the important features of the section in the Glen Burn is the short space of conformable strata which intervenes between the Upper Old Red Sandstone, with its peculiar fish-fauna, and the Carboniferous series, where the fishes are so remarkably different.

It is true, as will be afterwards pointed out, that the lowest subdivision of the Carboniferous system, the Calciferous Sandstones, is abnormally thin in this district, and that a vast period of geological time must here be unrepresented by stratified deposits. Nevertheless, even where the Calciferous Sandstones attain their maximum development, their fauna presents so great a contrast to that of the Upper Old Red Sandstone as to show either that the two formations were really separated by a great interval of time, or that the physical conditions under which they were respectively accumulated were so entirely different as to involve a wide divergence in organic forms.

To the east and west of the admirable section in the Glen Burn, the same strata may be examined in numerous less extensive and continuous exposures. Immediately to the east of the gorge last referred to, the white and yellow sandstones project in a succession of rounded buttresses from the heathery slopes of the West Lomond. The Kilgour Craigs, further east, lie along the same outcrop, and still further, in the same direction, a good section of the strata from the black shales near the base of the Carboniferous system down into the red sandstones of the Upper Old Red Sandstone, will be found in the Maspie Den, above Falkland House.

On the west side of the Glen Burn, the upper white and yellow sandstones, with the red series below them, continue to show themselves along the slopes of the Bishop Hill and Benarty. In this part of the district, the cornstone zone has been specially well developed, and the calcareous parts of it have been sufficiently pure to have led to the opening of the rock in former years along a line of shallow quarries and pits. Its outcrop may thus be traced along the northern front of Benarty Hill from above East Brackly to West Mains, and again on the south side of the hill above Ballingry. The seam lies on white and yellow sandstones, and is much brecciated and in places strongly nodular. It is occasionally so exceedingly compact as to give sparks when struck with a steel hammer. No trace of fossils has been noticed in it. It is overlain by a black shale, and that by greenish and blueish shales and clays, with cement-stone nodules and bands of the true Cement-stone type of the Carboniferous system.

To the south of Benarty Hill the regularity of the stratigraphical succession has been interrupted by a line of powerful dislocation, which, by throwing down the Carboniferous formations on the south side, has in some places brought the higher parts of the Carboniferous Limestone series, and even a portion of the Coal-measures, against the Upper Old Red Sandstone. This fault probably attains its maximum amount of throw about a mile to the south-east of the southern end of Loch Leven, where the displacement must exceed the total thickness of all the subdivisions of the Carboniferous system up to the lower members of the Coal-measures—that is, probably between 4000 and 5000 feet.

On the north side of this great line of fracture, the higher portions of the Upper Old Red Sandstone and their passage into the base of the overlying system can be well seen at several places. On the south side of Benarty Hill, for example, the yellow sandstones, together with the overlying cornstone, so well exposed on the north side, reappear for a short distance between the outcrop of the Carboniferous strata and the line of the fault. But nine miles further to the west, some more important exposures may be examined in the Gairney Glen, and in the ravine of the River Devon below Caldron Linn. The cornstone is there well developed between Mossendgreen and the Devon, near Muckart, passing under the clays and sandstones of the Carboniferous basement group and overlying the white and red sandstones of the Upper Old Red Sandstone.

In the midst of this tract there rises to the surface, at the Monk's Grave, a small knob of the volcanic series of the Lower Old Red Sandstone already described. The presence of this inlier shows on what an unconformable and uneven surface the Upper Old Red Sandstone must be resting. Instead of attaining a thickness of 1500 or 2000 feet, as in the Lomond development, the formation cannot be here more than 500 feet thick, and is possibly a good deal less. This detached portion of Upper Old Red Sandstone is about two miles long and half a mile broad. On the north side it passes conformably below the Cement-stone group, which is immediately thrown down against the volcanic series by the great boundary fault already referred to. On the south side it is cut off by another powerful dislocation, which brings against it the higher parts of the Carboniferous Limestone and the Millstone Grit.

The area of Upper Old Red Sandstone, already alluded to, on the north side of the Ochil chain, lies rather beyond the limits of the district described in the present volume. It will be more appropriately treated in a subsequent Memoir dealing with the ground to the north.

CHAPTER V.

The Carboniferous System—Calciferous Sandstone Series.

THIS assemblage of formations is the most important in the whole district, from an industrial point of view, while in geological variety and interest it surpasses all the others. In the following account of it, a general table of its subdivisions will first be given, and each of these will then be described in order, beginning with the lowest. One of the most striking features of the Carboniferous system as developed in Fife is the enormous amount of igneous material associated with it. This material may be conveniently arranged in two divisions—(1st) that which was erupted contemporaneously with the strata among which it lies, and (2nd) that which was intruded into the strata after their deposition. The former division will be taken together with the strata among which its several members occur, so that the continuous geological history of the formations may be satisfactorily followed. The latter division will come more conveniently for description after an account has been given of all the sedimentary formations in which the intrusions have taken place.

TABLE of the Carboniferous System in Central and Western Fife.

Sign on Map.	Groups of Strata.	Localities.
	COAL-MEASURES.	
$d^{5'}$	*b*. Red, purple, and white sandstones, fireclays, shales and marls, with plant-remains and thin coals. 1000 feet. (This group appears to be equivalent to the "Middle Coal-measures" of England.)	Coast between Wemyss Castle and Scoonie Links. Not seen in any other part of the district, except in a small outlier near Kinglassie.
d^{5}	*a*. White and grey sandstones, black shales, oil-shales, ironstones, fireclays, and workable coal-seams. 1750 feet. (This division may be equivalent to the "Lower Coal-measures" of England.	Coast from west of Dysart to Wemyss Castle and inland by Thornton to Markinch, Kennoway, and Lundin, and westward beyond Kinglassie.
	MILLSTONE GRIT.	
d^{4}	White, grey, and reddish sandstones, fine quartz-conglomerates, and seams of black shale. 700 feet.	Coast for a length of 450 yards between Pathhead and Dysart, whence the strata strike inland to Markinch; not well shown elsewhere in the interior.

Sign on Map.	Groups of Strata.	Localities.
	CARBONIFEROUS LIMESTONE SERIES.	
	c. Group of sandstones and shales, with upper thin marine limestones (Levenseat seam, Gair or Janet Peat seam, and Index seam) and thin seams of coal. 1000 feet.	Coast at east end of Pathhead; thence north to Stenton and westward by Kinglassie to Capeldrae.
d²	*b.* Group of white and yellow sandstones, shales, and fireclays, with a number of workable coals ("edge seams") and ironstones. 1000 feet.	Coast from Pathhead to the Tyrie Bleach Works; thence inland through the collieries of Kirkcaldy, Clunie, Cardenden, Auchterderran, Capeldrae, Lochgelly, Kelty, Cowdenbeath, Fordel, Halbeath, Dunfermline, Saline, Oakley, and Torryburn.
	a. Group of sandstones and shales, with lower marine limestones (Hosie Hurlet).	Coast between Kinghorn and Tyrie Bleach Works; thence inland by Tough to Lochgelly, and Cullalo Hills to Parkend, Duloch, Dunfermline, Charlestown, Lathalmond, Cowdens, Roscobie, Craigluscar, Scaurhill.
	CALCIFEROUS SANDSTONE SERIES.	
d¹′	*b.* Burdiehouse Limestone and Oil-shale group, composed of white sandstones and black shales, with the Burdiehouse or Burntisland Limestone. In the part of the district between Burntisland and Seafield this group has its sedimentary deposits in large measure replaced by contemporaneous lavas and tuffs. At the top of this group on the shore east of Kinghorn some bands of limestone full of marine fossils (Abden Limestones) make their appearance. They underlie the Hurlet Limestone, which is taken as the base of the Carboniferous Limestone series, but they are really parts of that series rather than of the present group.	Coast from Seafield, by Kinghorn, Pettycur, Burntisland, St. David's, and Inverkeithing to Charlestown; inland in a small inlier between Loch Fitty and the Roscobie Hills.
d¹	*a.* Cement-stone group, consisting of red, yellow, and mottled sandstones, red and green sandy clays or marls, and thin seams of cement-stone. This group is the eastward extension of the "Ballagan Beds" which underlie the volcanic sheets of the Campsie Hills. The extreme eastward prolongation of the Campsie volcanic series is found above this group in the present district. At the bottom of the red sandstones lies a remarkably persistent cornstone or sandy limestone, which in central Scotland is taken as the summit of the Upper Old Red Sandstone and base of the Carboniferous system.	Ravine of the Devon below Rumbling Bridge, Gairney Glen, northern and eastern slopes of the Cult Hill to the north of Saline, and the northern slopes of the ridge which includes Wether Hill, Scaur Hill, and the western flanks of the Cleish Hills to near Hardistown. On the north side of the Ochil chain at East Dron, near Bridge of Earn.

Calciferous Sandstone Series.

I. Cement-stone Group.

This characteristic subdivision attains a great development beneath the volcanic plateau of the Campsie Hills (Sheets 30, 31, and 39), but is lost under the Carboniferous Limestone series brought against it by a fault near Kilsyth, and under the plain of the Forth around Stirling. On the north side of the Campsie Hills it gradually disappears beneath the volcanic plateau, either because it thins away towards the east or because it has been overlapped by the lavas. About 17 miles further to the east, however, it comes once more to the surface in the ravine of the River Devon, where it has been exposed as the result of extensive denudation coming after a powerful fault, which has thrown out nearly all the great thickness of strata between this group and the Millstone Grit. The Cement-stone group retains here its normal lithological characters, which are well seen both in the course of the Devon, and in the tributary stream which flows through the Gairney Glen. At the base, several bands of reddish nodular cornstone (4 in Fig. 4), with purple and red calcareous sandstones, form the characteristic upper limit of the Old Red Sandstone, and pass under green shales and marls, with thin courses of cement-stone. These strata (5 in Fig. 4) dip in a northerly direction at angles of from 12° to 20°, and are interrupted by the thick doleritic sill (7 in Fig. 4), which forms the waterfall of the Caldron Linn. Above that igneous mass they again appear in the river-bed with a dip of not more than 8°–10°, until they are thrown down by the fault which brings them against the volcanic series of the Lower Old Red Sandstone (1 in Fig. 4) at Dalkeith, a little below the Rumbling Bridge.

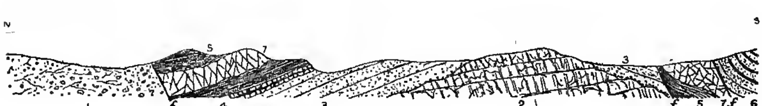


Fig. 4.—Section of the ground to the south of the Rumbling Bridge.
1. Volcanic agglomerates, and 2, Andesite lavas, of the Lower Old Red Sandstone series of the Ochil chain. 3. Upper Old Red Sandstone. 4. Cornstone. 5. Cement-stone group. 6. Millstone grit. 7. Dolerite sill. *ff.* Faults.

East of this section the ground is obscured by drift, but two miles further on excellent exposures of the group have been cut open by the streams which descend the northern slopes of the Cult Hill and of the hills between Meadowhead and Hardistown. The actual base of the strata is not seen here. The slopes are somewhat obscured with drift, and, besides, the fault along the base of these slopes cuts out more and more of the Carboniferous strata as it goes eastward. Possibly the Upper Old Red Sandstone may be represented by some red sandstones which crop out at the bottom of the northern declivity of the Cult Hill above Pow.

The most interesting sections of the Cement-stone group in this part of the district are to be found in the water-course which descends from Scaur Hill and in the Georgetown Burn, which reaches the plain east of Hardistown (Fig. 5). In the lower part of the Scaur Hill Burn, green, blue, and red clays or shales, with bands and nodules of cement-stone and beds of white sandstone, display the typical characters of this group. Though on the whole unfossiliferous, they have furnished to the Survey Collector, Mr. D. Tait, some ostracods, including *Leperditia Okeni*, and a *Beyrichiopsis*, and some fish-scales belonging to *Elonichthys*. These strata are succeeded by and pass up into well-bedded dull green tuffs, which have a total thickness of more than 100 feet, and seem to be made up mainly of decomposed andesitic material, but include abundance of pieces of cement-stone, cornstone, sandstone, and other sedimentary rocks. The fine vesicular pumice, so characteristic of the tuffs in the Burdiehouse Limestone and Carboniferous Limestone groups, has not been recognised here.

The upper part of the tuff is calcareous, and includes a thin limestone which has once been worked on the slope of Cult Hill. Immediately above this part of the section, the stream is crossed by a large fault which comes from the southern end of Cult Hill and throws down the rocks to the south (8 in Fig. 5). It here brings the Hurlet Limestone of the Scaur Hill Quarry on a level with the tuffs just described. But as it slants a little to the south-east, it allows a higher part of this volcanic series to be seen at the north end of that quarry. The Hurlet Limestone, with its overlying shales and doleritic sill, is there abruptly truncated and brought down against a rock of felsitic or rhyolitic character, belonging to the lavas which, in the section in the Georgetown Burn, lie immediately upon the tuffs. The rock is here so much decomposed that fresh determinable specimens can hardly be procured. It is yellowish, greyish, and pinkish in colour, according to its degree of weathering, meagre and trachyte-like. It presents plentiful lines of flowstructure, which are sometimes curved. A thin section was made from one of the freshest pieces of the rock that could be procured and was examined by Mr. Kynaston, whose description of it will be found in the Appendix (p. 260).

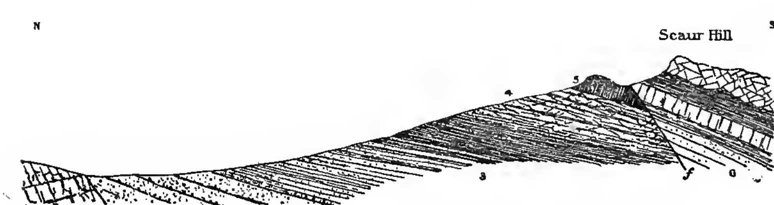


FIG. 5.—Section from Aldie Castle to Scaur Hill.

1. Volcanic series of Lower Old Red Sandstone. 2. Upper Old Red Sandstone. 3. Cement-stone group. 4. Tuffs with shaly intercalations. 5. Rhyolitic and basaltic lavas. 6. Burdiehouse Limestone group. 7. Hurlet Limestone. 8. Black shales. 9. Dolerite sill of Scaur Hill. *ff.* Faults.

This zone of lava can be followed along the hillside by means of occasional protruding knobs for nearly a mile, till it is cut by the ravine of the Georgetown Burn east of Hardistown (Fig. 6). In this course, owing to the general dip of the strata, it gradually descends the slope, and sinks gently under a group of white and yellow sandstones (6 in Fig. 6), which form a well-marked platform at the base of the Burdiehouse Limestone group of this district. These strata followed the eruption of the lava below them, since they contain pebbles of it. Further down the stream a remarkable bed of coarse conglomerate occurs (No. 5 in Fig. 6), the precise stratigraphical position of which is not clearly displayed in the water-course. It appears to be quite local, and not improbably is an expansion of the pebbly zone at the base of the sandstones just referred to. It is about 12 or 15 feet thick, and consists of well-rounded stones chiefly derived from the underlying felsitic lava.* Some of these blocks are well-worn boulders three feet in length.

The occurrence of this conglomerate indicates an interesting episode in the history of early Carboniferous sedimentation in this district. It shows that the underlying lava must have been exposed to denudation for a considerable interval, during which its detritus was thoroughly ground down and its blocks were converted into rounded boulders. No similar evidence of strong wave- or current-action has been met with in any other part of the region, the sediments generally indicating comparatively gentle conditions of accumulation.

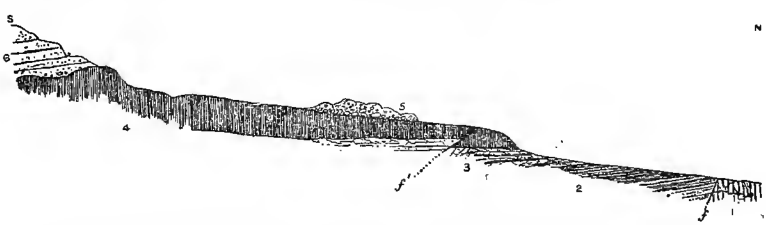


FIG. 6.—Section in Georgetown Burn, west end of Cleish Hills.
1. Volcanic series of Lower Old Red Sandstone. 2. Cement-stone group. 3. Tuffs and shales. 4. Felsitic (Rhyolitic) and Basaltic lavas. 5. Very coarse conglomerate. 6. Yellowish sandstone (Burdiehouse Limestone group). *f'*. Reversed Fault. *f*. Fault.

The lava-zone is well exposed at, and for some distance above, a waterfall in the Georgetown Burn (No. 4 in Fig. 6). It shows considerable variation in external aspect of its component rocks. In some places these are compact and blue, in others they weather into spheroidal forms, with a dull green outside, like many basalts and dolerites. Again they resume their felsitic or rhyolitic character with flow-structure. There are probably at least two flows comprised within the sheet, which is not more than 15 or 20 feet thick. As fresh specimens as could be procured from two distinct types of the rock were examined under the microscope by Mr.

* See Appendix (p. 261) for Mr. Kynaston's description of the microscopic structure of some of these blocks.

Kynaston, who found that one of them was a compact felsite with small pink crystals of orthoclase, while the other was more closely related to the basalts.* It is interesting to find representatives both of the acid and basic lavas within such a thin volcanic zone.

This lava-sheet rests upon the tuffs (No. 3 in Fig. 6). At the waterfall it is ruptured by a small reversed fault, and other signs of disturbance may be observed. The tuffs are here exceedingly fine in texture and are interleaved with layers of dark-purple and grey shales. So rapidly do the volcanic and ordinary sediments alternate that in 14 inches of strata 10 layers of tuff may be observed, ranging from less than a line to an inch in thickness. Below these alternations the ordinary dull green granular tuff sets in, followed by the Cement-stone group, until the Carboniferous rocks are brought by the fault to abut against the andesites of the Lower Old Red Sandstone (No. 1 in Fig. 6).

The stratigraphical position of this volcanic intercalation can be precisely fixed. The tuffs overlie and are interstratified with the Cement-stone group. They contain abundant fragments of the strata of that group, the older parts of which must thus have been blown out by the explosions that discharged the tuffs. Again, immediately above the lava that overlies the tuffs, come the yellow sandstones at the base of the Burdiehouse Limestone group. These volcanic rocks thus occupy a position similar to that of the volcanic plateau of the Campsie Hills, and it is not improbable that they may be an eastward extension of that volcanic area. They are undoubtedly the oldest Carboniferous volcanic rocks yet detected in Fife. The next in point of antiquity are those of the Burntisland district, which belong to the Burdiehouse Limestone group.

Unfortunately, in none of these sections at the west end of the Cleish Hills is the Cornstone to be observed, which forms so convenient a downward limit to the Carboniferous system. But a few miles to the east, as has been already stated, this important stratigraphical horizon crops out in full force on the northern and southern slopes of Benarty Hill. Only the very base of the Cement-stone group is there visible. At the west end of Navity Hill, and due north from Ballingry House, where the clays and cement-stones make their appearance, they have been found by Mr. Peach and Mr. Grant Wilson to include some thin intercalations of volcanic tuff, which are evidently a prolongation of the more fully developed volcanic group at the west end of the Cleish Hills. This outcrop is the most easterly limit to which the volcanic eruptions of the Campsie platform have been traced.

East of Navity Hill the Cement-stone group rapidly thins away. On the Bishop and West Lomond Hills, its position is indicated by the occurrence of green clays and decomposing cement-stones immediately above the cornstone. The slopes are, unfortunately, so obscured by landslips and herbage that

* Appendix, page 260.

continuous sections are hardly to be found. But between the top of the Cornstone and the base of the black shales which underlie the Hurlet Limestone there can scarcely be more than about 60 or 70 feet of strata, of which some part consists of the sandstones of the Burdiehouse Limestone group. The cement-stones have not been recognised further east, though possibly a careful search among the gullies and water-courses along the hill-slopes may yet reveal a still more attenuated representation of them.

II. Burdiehouse (Burntisland) Limestone and Oil-shale Group.

This subdivision presents greater variety than any other in the Carboniferous system of Fife, on account of the remarkable succession of contemporaneous volcanic rocks which it includes. As shown on the map (Sheet 40) it is developed along the coast on either side of Burntisland, whence it stretches inland for five miles. It continues westwards along the coast as far as Charlestown (Sheet 32). The cause of this distribution will be at once understood by a reference to the geological structure of Midlothian, on the opposite side of the Firth of Forth. In that region an important anticlinal fold coincides with the general line of the Pentland Hills, along which Upper Silurian and Lower Old Red Sandstone rocks are brought up to the surface, while the various members of the Carboniferous system are thrown off on either side. This axis is prolonged across the firth, and, bending a little west of north, reaches the Fife coast at Burntisland. It then turns round towards N.N.E. and runs for at least twelve miles inland till it is lost among the hills beyond Markinch.

It is by means of this structure that the area of the Burdiehouse Limestone group is so sharply defined. The anticlinal fold, in gradually "nosing out" towards the north, allows the Hurlet Limestone (which marks the upper limit of the group) to completely encircle the Raith Hills, north-west from Kirkcaldy. But the anticline continues to be traceable in the higher members of the system, which are folded over it. Thus, the Limestone series is prolonged in a tongue up to Stenton. The Millstone Grit in like manner is extended up to Markinch, while the Coal-measures are thrown westwards into the detached basin of Kinglassie. It is deserving of note, however, that just before the fold ceases to be satisfactorily traceable it seems to increase in its effects, for at Markinch it brings up once more to the surface a portion of the strata below the Hurlet Limestone, including a seam of oil-shale 6 inches thick. But this apparent increase may be mainly or entirely due to the influence of one of the largest dislocations in the district which, bounding the northern limit of the Kinglassie coal-field, stretches by Markinch, where it throws the Coal-measures against the Hurlet Limestone and Burdiehouse Limestone group, to the sea at Scoonie Links.

It will be seen from the map that the composition of the

Burdiehouse Limestone and Oil-shale group is strikingly different on either side of a line drawn from Burntisland north-westward to Beverkae. On the east side it is made chiefly of volcanic rocks which replace the sedimentary strata, while to the west it contains hardly any volcanic intercalations, though it has been invaded by a number of intrusive sills and bosses. The contrast between these two types of the formation will be appreciated by comparing Figures 7 and 8. The former of these diagrams represents the sequence of strata to the west of Burntisland, along a line which is free from volcanic intercalations, while Fig. 8 is drawn through the very heart of the volcanic development. It will be convenient to take first the western or more usual sedimentary development of the group.

A. DISTRIBUTION TO THE NORTH AND WEST OF BURNTISLAND: SEDIMENTARY DEVELOPMENT.

Nowhere in this part of the district is the bottom of the group exposed. Possibly the whole visible thickness of strata may amount to 2000 feet. The lowest rocks now to be seen are those on which the town of Burntisland is built. They consist of sandstones, shales, and thin impure limestones, but not of the Cement-stone type. They are invaded by three thick sills, which will be subsequently referred to in connection with the intrusive rocks. These strata are seen both below and above the middle sill, greatly indurated by the eruptive rock. They dip towards the north-west under the alluvium between Seamills and Colinswell, and on the north side of the bay are succeeded by other sandstones and shales, with seams of coarse nodular limestone. One of these limestones, well exposed in the railway at Colinswell, consists of several bands, having a total thickness of about six feet and intercalated among black shales containing plant-remains. Its bands are finely

FIG. 7.—Diagram-section of the ground to the west of Burntisland.

1. Sandstones, shales, &c., of Burdiehouse Limestone group. 2. Burdiehouse or Burntisland Limestone. 3. Hurlet Limestone at the base of the Carboniferous Limestone series. 4. Coal-bearing measures of the Dunfermline Coal-field. 5. Sills of dolerite, &c., the highest of which forms the range of the Cullalo Hills.

laminated and display a remarkable brecciated structure, the laminæ having been curved, broken up, and re-cemented in similar limestone. Other limestones, formerly exposed close to the roadside leading east from Burntisland, contain *Myalina* and other marine organisms. A considerable thickness of yellow shaly sandstones, with dark carbonaceous layers, now supervenes. These strata have been laid open in the quarries of Kilmundy and

Grange. Their most interesting geological feature is the fact that they include the horizon of the Burdiehouse Limestone, represented here by at least three bands, of which the two lower are intercalated in an arenaceous instead of, as usual, in an argillaceous succession of deposits. The section through the two quarries is represented in the following table, though some of the ground being concealed, certain parts of the thickness can only be given in approximate numbers :—

Black shale.
White sandstone of Grange Quarry (100 feet or more).
Shales and ironstones (a few feet).
Limestone (Grange or Burntisland Limestone, 18 feet).
Shales and sandstones (a few feet).
White false-bedded sandstone of Kilmundy Quarry (perhaps 30 feet).
Limestone like that above ($7\frac{1}{2}$ feet).
Sandstone (6 feet).
Limestone of the same character (2 feet).
Sandstone.

These limestones present the closest lithological resemblance to the typical rock of Burdiehouse. They are fine-grained dull grey or cream-coloured, often well banded with layers of darker carbonaceous material. They abound in remains of fragmentary plants, together with entomostraca and the scales, teeth, and bones of small fishes. These fossils likewise agree with those of the Burdiehouse seam. They consist chiefly of plant-remains, especially *Calymmatotheca* (*Sphenopteris*) *affinis*, *S. crassa*, *Lepidodendron veltheimianum*, *Lepidostrobus variabilis*, *Lepidophloios intermedius*, *Lepidophyllum lanceolatum*, *Asterocalamites scrobiculatus*, and other forms, which will be found more fully enumerated in the Appendix. Besides the vegetable-remains a limited fauna has also been obtained. It includes *Leperditia scoto-burdigalensis*, *L. suborbiculata*, *Spirorbis carbonarius*, *Eurynotus crenatus*, *Elonichthys Robinsoni*, *Rhadinichthys ornatissimus*, *Megalichthys*, *Rhizodus*, *Gyracanthus rectus*, *&c.*

The thickest limestone has been extensively worked in this neighbourhood, both in open quarries and by mines. Beginning on the west at Dalachy a continuous line of excavations has been carried on by Newbigging, Kilmundy, and Grange, until the limestone is cut off by the agglomerate of The Binn. On the east side of that interruption the workings were resumed to the west of Brosyhall Quarry, and carried eastwards and then southwards by Dodhead until the series passed under the strip of blown sand below King Alexander's Crag. But these quarries have long been disused. The upper part of the limestone and its overlying black shales are well seen in the old quarry east of Dodhead. An interesting feature in this section is the occurrence of a thin sill of basic intrusive material, so evenly intercalated among the shales that it might at first be mistaken for a harder rib of sediment. But at the southern end of the quarry the really intrusive nature of the sill is shown by its descending abruptly as a tortuous vein which traverses the shales (Fig. 16). Numerous other intrusions of similar material

occur throughout the tract through which the outcrop of the limestone runs. The relations of these injections are well seen on the low cliff to the south of Dodhead farm, where an irregular sheet of basalt has invaded and baked a set of shales and sandstones lying below the main limestone (Fig. 17.) Two thin limestones may there also be seen, the upper partly cut out by the igneous rock, and the lower surmounted by a thin sill which runs parallel with its outcrop.

So much have the strata of this district been invaded by igneous rocks and displaced by faults that it is difficult to make out the structure of all parts of the ground, and to place separate outcrops in their proper stratigraphical position. Thus, 500 yards to the north-east of the Grange Quarry, a limestone has been extensively quarried behind The Binn. It is a yellowish well-banded rock, containing cyprids and interleaved with ashy seams. A thinner seam of sandy limestone and calcareous conglomerate, with layers of tuff, crops out a little to the west at Silverbarton. These limestones lie among sandstones like those of Grange and Kilmundy, from which, however, they differ in their inclusion of volcanic detritus, due possibly to greater proximity to a volcanic orifice. It may be that these more northerly outcrops belong really to the Grange and Kilmundy seams, brought up again by some large east-and-west fault, the exact position of which has not been determined. On the other hand, there are undoubtedly various limestones on horizons in the Burdiehouse Limestone group other than those of the Grange and Kilmundy seams. Reference has already been made to the limestones of Colinswell and those with *Myalina* which underlie these seams. Another limestone, probably on a higher horizon, may be seen immediately underlying the tuff at Dunearn Cottage; still another, to be immediately more specially referred to, occurs at Port Haven and on the shore of Braefoot Bay, west of Aberdour. It will be shown also that among the sedimentary interstratifications in the great volcanic pile between Burntisland and Seafield seams of limestone make their appearance on different platforms.

Above the main Burntisland Limestone, at a distance of about 150 feet, a seam of oil-shale occurs which has been worked over the ground to the east of The Binn. It was found to dip a little to the west of north at an angle of about 10°, and was followed by a mine driven a little east from Binnend along the dip for about 900 yards to a point about 200 yards N.E. from the farm buildings of Common. At a distance of about 350 yards from the mouth of the mine a fault was encountered, running in an E.N.E. direction, with a downthrow of 10 fathoms to the south. About 330 yards further north another dislocation was met with, trending E. and W., with a downthrow of $8\frac{1}{2}$ fathoms to the south. The shale was worked eastwards as far as the Gallowhill Plantation, where it was found to be inclined towards E.S.E. under the volcanic ridge.

The crop of this seam can be followed from the eastern margin of The Binn agglomerate parallel with that of the limestone below it. It is thrown down to the side of the high road by a fault which

runs in a north-easterly direction from the old limestone quarry of Brosyhall, where its position is seen, to the lava-sheets at Rodanbraes. But the outcrop immediately resumes its previous course, until below Whinnyhall it wheels round with the limestone and strikes southward in the direction of the shore at Kingswood Cottage.

Some miles to the west a group of black shales, which may be the same as those of The Binn, are exposed in a cutting of the old mineral railway about a mile north from St. David's. They include a seam of oil-shale, believed to be the Dunnet shale of the Lothian fields. If these are a prolongation of the Burntisland shales, the limestone should pass somewhere through the Donibristle grounds. But it has not yet been traced there. The shore-section between Aberdour and Donibristle House presents an undulating succession of strata, consisting chiefly of sandstones with thin shales and several thick intrusive sheets of coarsely crystalline dolerite. These strata dip northwards at Whitesands Bay. They are folded into an anticline in Barnhill Bay and Port Haven over the sill of Charles Hill, into a syncline in Dalgety Bay, and once more into an anticline at Donibristle. There can thus be no great thickness of strata exposed in this part of the shore-line.

Perhaps the most interesting stratum in this coast-section is a thin limestone which is exposed upon the beach at Port Haven. It has yielded species of *Lepidodendron*, *Lepidophyllum*, *Lepidostrobus*, *Trigonocarpon*, several ostracods, *Lingula mytiloides* and *L. squamiformis*, some *Schizodus*-like lamellibranchs not yet determined, *Eurynotus crenatus*, and *Elonichthys*, sp. What may be a continuation of the same seam crops out on the shore of Braefoot Bay.

Where the sandstones and black shales turn over with a westerly dip at Donibristle they continue to incline in that direction, broken through by the massive east and west dyke of Downing Point, until they plunge rather steeply, and with some confusion of their bedding, under the tuff of St. David's—a remarkable deposit, of which an account will be given in the description of the volcanic series which is developed to the north and east of Burntisland (p. 76.)

To the west of St. David's some strata, still dipping to the north-west, and thus presumably higher than those that overlie the tuff, are exposed on the shore below Seafield Cottage. They include an interesting intercalation of one of the marine platforms which occur at intervals throughout the Calciferous Sandstone series. Besides plant-remains, together with shells of *Naiadites*, *Myalina*, and other forms that may mark lagoon conditions of sedimentation, there occur such unequivocally marine types as *Nautilus* or *Discites*?, *Orthoceras*, *Goniatites*, *Bellerophon*, *Murchisonia*, and *Pleurotomaria*. Plates of fishes are intermingled with the other organisms.

The huge dolerite sill which occupies the coast from Seafield round to St. Margaret's Hope, and on which North Queensferry and Inverkeithing are built, stretches northward to the great

alluvial plain of the old sea-terrace beyond Inverkeithing. It lies in a synclinal trough. On its western margin, sandstones and shales emerge from under the igneous sheet. At Rosyth, the dip turns over towards the west, and then the strata continue to undulate as far as Charlestown, where they pass under the Hurlet Limestone. They include some thin limestones, one bed of which covers a broad space of the foreshore west of Rosyth Castle. Among their fossils *Serpula?* and *Anthracoptera obesa* have been noted.

It will be observed that a large fault is shown on the map (Sheet 32) as traversing the hollow from Little Couston to the alluvial plain north of Inverkeithing Junction. The effect of this dislocation is to cut off the Calciferous Sandstone series towards the north by bringing down against it the Carboniferous Limestone series with its coals. The continuation of the fault in a westerly direction has not been satisfactorily traced. Possibly the faulted strata on the beach to the west of Rosyth may mark where it passes under the firth. But the amount of its throw seems to be lessening in that direction.

An interesting section showing the nature of the strata in the upper part of the Burdiehouse Limestone group was obtained in 1892 by means of a boring made at the Elgin Bleachfield, near Dunfermline, by Messrs. Thomson Brothers, who have been good enough to supply the following journal of the strata passed through:—

	Fms.	Ft.	In.
Surface	0	4	0
Sandy clay	2	2	0
Sand and gravel	0	3	0
Blaes (shale)	1	2	4
COAL	0	0	9
Fakes (shaly sandstone)...	1	1	8
Blaes	1	3	0
Fakes and sandstone	1	4	2
Sandstone	4	5	4
LIMESTONE (Hosie)	0	2	6
Limey Fake (calcareous shale)... ...	0	2	0
LIMESTONE	0	2	0
Sandstone	3	2	6
Fakes	1	5	0
Fakey blaes and balls (ironstone) ...	2	1	0
Blaes and balls	8	2	2
LIMESTONE (Main or Hurlet)	4	0	3
Blaes	0	3	2
Fakes	0	2	8
COAL	0	2	0
Fireclay	0	0	9
Light fakes	0	2	0
Fakes and fireclay	3	3	6
COAL	0	0	10
Fireclay	0	2	3
COAL	0	0	7
Fakes and blaes	0	1	0
Sandstone	5	0	3
Fakes	0	1	0
Sandstone	4	3	11

	Fms.	Ft.	In.
PARROT COAL—Irony B.B. (Ironstone) ...	0	1	0
Fakes and sandstone	1	4	3
Blaes and sand-rib	0	5	4
Blaes	0	4	6
Fakes and sandstone	1	1	0
Blaes	0	4	0
COAL	0	1	0
Fakes and sandstone	0	1	6
Sandstone	3	3	11
Blaes	0	2	6
LIMESTONE	0	2	0
COAL	0	1	0
Sandstone	3	2	9
Fakes and sandstone	0	4	6
Fakes	0	4	10
Fakey blaes and iron-ribs	4	5	9
Blaes	1	3	0
LIMESTONE	0	4	0
"Whinstone" (the name popularly given to most igneous rocks in Scotland) ...	6	1	2
LIMESTONE	0	1	6
Blaes and balls	0	5	4
Limey fakes	0	0	11
COAL	0	0	6
Fakes and fireclay	0	1	6
Fakes and sandstone	2	5	11
Fakes and sandstone	3	5	3
Red and blue fakes and fireclay ...	3	3	11
Fakes and sandstone	0	3	0
Fireclay and balls	2	2	5
Limey fakes	0	2	4
Total	95	2	2

It will be seen from this section that below the Main or Hurlet Limestone, which was found to be 24 feet thick, two or possibly three other seams of limestone occur in a total thickness of about 300 feet of strata, together with no fewer than seven thin seams of coal. The lowest limestone lies immediately below a sheet of igneous material, which is probably an intrusive sill of dolerite. Whether this is a distinct limestone or is a portion of the seam above, separated by the injection of the sill, has not been determined. The limestones and coals pierced in this bore probably lie nearly on the same horizons as those which emerge from below the Hurlet Limestone on the coast to the east of Kinghorn. As will be more fully stated in the sequel, these limestones of the shore-section abound in fossils of the Carboniferous Limestone series, to which palæontologically they undoubtedly belong. But the Hurlet seam forms a horizon so well defined and so easily traced that, although it does not always mark the beginning of the distinctively marine type of sedimentation of the Carboniferous Limestone series, it has been found to be the most generally convenient line that could be adopted in mapping the base of that series throughout Central Scotland.

Returning now to the outcrop of the Burdiehouse Limestone

near Burntisland, and tracing the succession of strata in an inland direction, we find no continuous sections over the ground that lies to the north-west of the last appearance of the limestone at Dallachy, though the underlying rocks protrude through the drift in many places. Most of the exposures are of sandstone, on the whole inclined towards north and north-west. The strata are seen in the Humbie Wood; at many points between Montquey and Croftgarrie, especially on the farm of Balram, where they are interrupted by a number of sheets of tuff and small protrusions of basalt. A large dolerite sill is intercalated among them between the Burntisland reservoir and Whitehill, and other sills are interposed between Montquey and Crossroads. The most important zone among these sandstones is that in which the extensive quarries of Cullalo have been opened. This white sandstone forms a valuable building stone. It crops out along the Cullalo ridge, and stretches south-westward in the direction of Whitehill, though concealed in the southern part of its course under a slope of drift. At the farm of Cullalo it plunges beneath another sill, to the north of which white sandstones reappear with the same northerly dip at Cottown. These sandstones sink rather steeply below a group of black carbonaceous shales and ironstones, which may be seen by the side of the high road dipping north-west at from 30° to 50°. Towards their junction with another sill, the shales beneath it are much baked. This sheet of dolerite begins to the west of Otterston Loch, about a mile and a half north from St. David's, and runs continuously for six miles, when it unites with other intrusive masses about Auchtertool. The shales among which it has been injected, on the high road between Stewart's Arms Inn and Cottown, form the base of the Carboniferous Limestone series, for the Main or Hurlet Limestone lies there immediately on the top of the sill. As this band of limestone is traceable almost continuously round the volcanic area to the sea near Kinghorn, it forms a clearly marked limit to the Burdiehouse Limestone group.

Before considering the volcanic development of this group, which forms so striking a feature in the geology of the ground to the east and north of Burntisland, we may briefly notice the distribution and characters of the sedimentary phase of the group in other parts of the district. Two miles to the north of Dunfermline, owing to the uprise of a small dome of the lower part of the Carboniferous formations, the Burdiehouse Limestone group has been brought to the surface over a space of rather more than a square mile. The southern side of the dome is truncated by a large dislocation which coincides with the longer axis of Loch Fitty, and brings down towards the south the coal-bearing strata of the Dunfermline coal-field. The western side has been much invaded by intrusive igneous rocks. But round the north and east margins the upper limit of the group is defined by a nearly continuous outcrop of the Hurlet Limestone. Only the upper parts of the group are here exposed, consisting of sandstones and black shales. They are best

seen in the Meldrumsmill Burn, between Balmule Lodge and the alluvial plain at the upper end of Loch Fitty.

Reference has already been made to the appearance of a small inlier of the strata below the Hurlet Limestone at Markinch, brought up on the crest of the great anticline. The same limestone is continuously exposed for many miles along the higher slopes of Bishop Hill and the Lomonds, and again near Freuchie and Pitlessie. But though there is an unbroken and conformable sequence of strata along this escarpment from the limestone down into the Upper Old Red Sandstone, the Calciferous Sandstones are not well represented there. It has been already pointed out that the Cement-stone group may still be recognised on the slopes above Loch Leven, but in a greatly attenuated form. Immediately upon the green clays and decomposing cement-stones, which show the presence of that group, comes a series of black shales and seams of ironstone with lenticular courses of white or yellow sandstone. These strata contain abundant remains of plants, and evidently do not belong to the marine type of sedimentation, like the overlying Hurlet Limestone. They are a little more than 100 feet thick, and they not improbably represent the Burdiehouse Limestone group, which thus, like the cement-stones below, is rapidly dwindling away towards the east. But, besides diminishing in thickness, the group changes its lithological characters and its fossil contents. Its place in the east of Fife is taken by a very distinct series of strata which contain many marine limestones lying far below the Hurlet seam.

CHAPTER VI.

The Calciferous Sandstone Series—continued.

B. Burdiehouse Limestone Group to the East of Burntisland—Volcanic Development.

Having considered the western or sedimentary development of the Burdiehouse Limestone group, we may now proceed to discuss the volcanic development of the group in the area lying to the east and north of Burntisland.

Instead of an essentially sedimentary succession, that area presents us with an assemblage of rocks almost wholly of volcanic origin, among which the sedimentary materials form only occasional and subordinate interstratifications. These intercalations, however, are of extreme interest and importance, for they show that during the intervals between the eruptions sedimentation of the usual kinds took place within as well as without the volcanic area, and they furnish stratigraphical horizons by which the geological age of the volcanic history can be definitely fixed.

The volcanic rocks of the Burntisland district consist of three distinct groups. 1st, sheets of lava and tuff which were ejected from neighbouring volcanic vents at the time that the Burdiehouse Limestone group was in course of deposition. 2nd, masses of agglomerate and tuff filling up the actual orifices or chimneys of the volcanoes. 3rd, sills or intrusive sheets, bosses, and dykes of dolerite, basalt, or other basic igneous rock which never reached the surface, but were injected among the sedimentary and volcanic rocks at a greater or less depth and which have been at last exposed by the processes of denudation.

(i.) BEDDED LAVAS AND TUFFS.

The Lavas of this volcanic series are all of basic composition, and may be included in the family of basalt, but they manifest various divergences of internal composition and structure, which, according to the classification of Dr Hatch,* may be grouped under at least two types.

(*a*) *The Dalmeny type*—olivine-basalts with a ground-mass that shows granular or idiomorphic augite and encloses as porphyritic constituents abundant olivine, less augite, and little or no felspar. This variety, which is one of the most abundant among the Car-

* Given with modifications by Mr. W. W. Watts, in *Ancient Volcanoes of Britain*, Vol. I., p. 418.

boniferous puy-eruptions of Central Scotland, constitutes the great majority of the lavas of the Burntisland district. Admirable examples of it, both in the fresh and in the decayed condition, may be seen in the coast-section between Pettycur and Kinghorn.

(*b*) *The Picrite type.* Occasionally the basalts assume a still more basic character and approach picrites in composition. But no sharp line can be drawn between them and the others, the difference being for the most part discernible only with the microscope. The rocks of the present type present a ground-mass of granules of augite set among lath-shaped felspars, and as a porphyritic constituent contain much more olivine than augite. A rock of this type may be seen among the Abden reefs to the east of Kinghorn. The lowest basalt of King Alexander's Crag, west of Pettycur, approaches the same type, which it serves to connect with that of Dalmeny. Other types of composition and structure are found among the intrusive rocks, as will be explained in the sequel.

FIG. 8.—Diagram-section of the ground to the East of Burntisland.

1. Sandstone and shale of Burdiehouse Limestone group. 2. Burdiehouse Limestone. 3. Basalts and tuffs with occasional intercalations of sandstone, shale, coal, and cyprid limestone. 4. Marine limestones of the coast east from Abden Rocks. 5. Hurlet Limestone. 6. Coal-bearing measures of the Kirkcaldy coal-field. 7. Volcanic neck south of Dodhead. 8. Burntisland sills of dolerite (as in Fig. 7).

The characters of the lavas in the field will be best understood from the detailed account of them, which will be given in subsequent pages, when the coast-section between Burntisland and Kirkcaldy is described. It may be enough to state here that a large number of them are thoroughly vesicular from top to bottom, and now exist as dull dirty-green amygdaloids. These may be conveniently termed Earthy Basalts from their decayed condition. Others are fresh compact blue or black basalts, with a jointed structure which sometimes passes into well-developed columns. Some sheets consist partly of the earthy vesicular and partly of the fresh compact rock, the fresh portions being usually surrounded by the more decayed amygdaloid. In most cases, the top and bottom of the lava-sheets are strongly vesicular, often passing into a rough slaggy or clinker-like structure. A remarkable feature of many of them is their subdivision into large irregular sack-like or pillow-shaped blocks, which may have their central portions more largely vesicular than the rest. (Fig. 13.) These ellipsoids were formed during the flow of the still moving lava along the floor of the lagoon or sea. The interstices between them have often been filled in with fine tuff, which was stratified horizontally from side to side in the fissures before the lava was covered by the next outflow of molten material. In some cases portions of still fluid lava in the

heart of the mass were forced into the interstices, and now appear as veins of finely cellular basalt. The lava-sheets range from 8 or 10 to 40 feet or more in thickness.*

In the inland tract of country lying to the north-east of The Binn of Burntisland, and stretching to Kirkcaldy, it is not always possible satisfactorily to discriminate between true lavas and intrusive sills, inasmuch as the lithological characters of many of the rocks are sometimes so similar, and there is so great an absence of clear sections, which would allow the stratigraphical relations of the successive sheets to be ascertained. Hence, it may eventually be discovered, when better evidence is available, that the igneous rocks cover even more space than has been allotted to them on the map, and that portions of them which have been coloured as contemporaneous lavas are really sills and *vice versâ*. Among such changes may be the transference of one of the sheets south of Balwearie Castle, two miles west of Linktown, from the lavas to the sills. It has been mapped as a lava from its amygdaloidal character and general external resemblance to the undoubted lavas of the clear shore-section. But its internal structure, as revealed by the microscope, shows it to differ from the other lavas and to belong to a type which is characteristically represented in the intrusive sill of Binny Crag, in West Lothian. It contains no olivine, but presents a ground-mass consisting of granular augite, felspar-needles, and magnetite, with some interstitial matter, while felspar and occasionally a little augite are dispersed porphyritically through the rock. The distinctions that may be drawn between sills and lavas will be more fully considered in a later part of this volume.

The Tuffs of the Burntisland district are characteristically basic, seeing that they have been derived from the explosion and trituration of such rocks as now form the interstratified lavas. Their most abundant and conspicuous lapilli consist of a pale grey, whitish, or greenish basic pumice, crowded with cells or pores which are often so minute and closely aggregated that in a thin section under the microscope the material looks like the finest thread-lace. Sometimes the tuffs contain a good deal of what must have been originally a basic glass, but which has been altered into a dull palagonitic substance. They vary in texture from the finest volcanic dust up to coarse agglomeratic or brecciated masses. As might be expected where such materials have been showered over a water-basin, on the floor of which ordinary mechanical sediment was accumulating at the time, the tuffs frequently contain an admixture of such sediment, and by the cessation of their volcanic ingredients they pass naturally and insensibly into sandstone, shale, fireclay, and limestone.

In connection with these pyroclastic materials, reference may be made here to a specially interesting indication of volcanic activity

* For accounts of ellipsoidal structure in basalts and diabases see F. L. Ransome, *Bull. Geol. Univ., California*, No. 7 (1894); J. J. H. Teall and H. Fox, *Quart. Journ. Geol. Soc.*, xlix. (1893), p. 211; A.G., *Ancient Volcanoes of Britain*, vol. i., pp. 25, 184, 193; J. Clements Morgan, *Monograph, No.* xxxvi., *of U.S. Geol. Surv.* (1899), p. 112.

which may from time to time be observed as the cliffs and shore-sections are denuded. Ejected volcanic blocks may be noticed, which have fallen into ordinary sandy or muddy sediment, and have, by their weight and the force with which they reached the water-bottom, crushed in the layers of soft strata below them, while the layers above them pass on undisturbed. A good illustration of this structure, which was observed in the year 1864, is represented in Fig. 10. Another example was noted in the year 1879 on the shore at Pettycur and is shown in Fig. 8[a]. The block

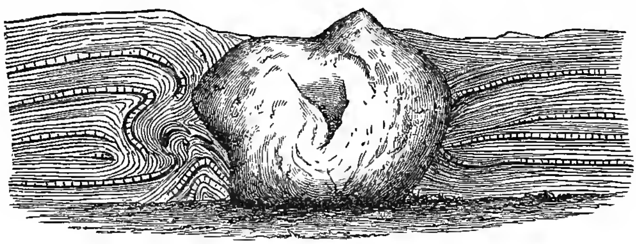


FIG. 8A.—Ejected Volcanic Block in Shales, Shore, Pettycur, Fife.

of basalt here figured measured 17 inches long by 15 inches broad and 12 inches thick. It must have descended with considerable impetus upon the still soft sediments, which have been consequently broken through and contorted.

The lowest lavas of the great volcanic pile, which extends to the east and north of Burntisland, are met with a little above the horizon of the oil-shale and black shales which overlie the Grange Limestone. They begin on the coast at Kingswood Cottage, beyond the east end of Burntisland, and with a general easterly dip continue eastward until they pass under the Hurlet Limestone. They thus form a total mass of about 1500 feet of volcanic material, lying between that limestone at the top and the Burdiehouse Limestone below. They are admirably exposed on the sides and escarpments of the hills, and still more clearly along the shore, where they form low cliffs and tide-washed reefs. Almost every bed in the whole series can thus be examined. As this section is undoubtedly the most instructive in Britain for the history of volcanic action during the Carboniferous period, it may be useful to give here a detailed account of it, bed by bed.

Unfortunately, the very bottom of the volcanic pile is concealed by blown sand at Kingswood Cottage. But probably only a few yards are here lost to view. The first rocks that can be seen are lavas, and from where they make their appearance the sequence of beds is continuous in the following ascending order:*—

* This interesting coast-section was briefly described by Dr. P. Neill in his translation of Daubuisson's *Basalts of Saxony*, Edinburgh 1814, note f., p. 215, but, being wedded to the Wernerian doctrines, he enumerates the successive beds without any reference to their volcanic character. A more just appreciation of the history of the rocks was formed by Ami Boué in his *Esquisse Géologique sur l'Ecosse*, Paris (about 1820), p. 471, and by C. Maclaren in his *Geology of Fife and the Lothians* (1839), pp. 82, 107. For the sake of convenient reference, the several beds of rock in the section are numbered consecutively

5. BASALT, of specially basic composition (picrite-type). In some places the rock has a more closely crystalline texture, and is dark and comparatively fresh; elsewhere it assumes the dull greenish, earthy aspect, so characteristic of many of the lavas of this coast. It is highly amygdaloidal, especially towards the top. Its hard, black, compact portions break with a splintery fracture, and show on their freshly-fractured surfaces abundant grains of olivine. The coarser parts include large masses of more compact basalt,† the two varieties of texture passing insensibly into each other, as in the Tertiary lavas of Auvergne and in the *coulées* of many still active volcanoes, masses of compact, black solid material are wrapped round in, and shade off into the rough scoriaceous portions. It is thus interesting to recognise, one after another, the various types of structure of recent volcanic rocks among these ancient lavas of the Fife coast.

The outflow of this basalt was marked by a pause in the eruptions which is recorded in an intercalation of muddy sediment.

6. BLUE SHALE. This band is not continuous, for it thins away higher up in the cliff, thereby allowing the basalt beneath it to be covered directly by the next lava above. The shale is not altered at its junction with the basalt on which its rests. But it is traversed and slightly indurated by veins of a soft earthy decaying material which have evidently descended from the overlying sheet. Beyond the part of the section where the two lavas come together, the shale re-appears at the west end of the cliff, associated with some grey shaly sandstone which lies on a hard rudely columnar basalt that assumes the earthy condition at the top.

7. BASALT, dull, green earthy, and amygdaloidal, 35 or 40 feet thick towards the east end of the cliff, but diminishing westward to not more than 8 or 10 feet, where it is surmounted by an inconstant parting of

8. GREEN SHALE (6 to 12 inches), not seen towards the east; much altered and involved above by the next outflow of lava.

9. BASALT, hard, black, crystalline, full of olivine; rudely columnar and weathering with a rough surface. Near the west end of the cliff, the top of this sheet sinks into a hollow in which a little shale and limestone have been deposited, but which is mainly filled up by the succeeding lava.

10. EARTHY BASALT, greenish and amygdaloidal. In rocks of this frequently recurring type the abundant amygdaloidal vesicles present extremely irregular forms, and vary in size up to nearly a foot in length by two or three inches in breadth. The kernels that line or fill them consist for the most part of calcite, while

from below upward, and the same numeration is adopted as is given in the abstract of the section published in my "Ancient Volcanoes of Britain," Vol. I., p. 470. It should be added that in that abstract No. 1 includes the strata below the Burdiehouse Limestone; No. 2 is the Burdiehouse Limestone of Grange, Kilmundy, Dodhead, &c.; No. 3 the black shales overlying the limestone; No. 4 the thick white sandstones of Grange, &c. The volcanic part of the section begins with No. 5.

† Boué has noticed this feature — "Cette roche empâte des masses d'un produit basaltique noirâtre qui ont tous les caractères d'être de formation contemporaine avec l'amygdaloïde," p. 473.

chalcedony, crystallised quartz, and green earthy decomposition products occasionally occur. Harder portions of this rock show on their weathered surfaces a vast number of minute round cavities which bear a striking resemblance to the vesicular pores of the harder portions of some of the Auvergne lavas. The term "earthy basalt," as above stated, is used here to discriminate the dull, decomposed, amygdaloidal lavas from the black, fresh, compact varieties. The two kinds of rock doubtless indicate some original difference in the condition of the magma at the time of outflow. But they pass into each other even in the same sheet, as in the case of the band now under consideration, which, like the lower sheet above referred to, includes large lenticular masses of good hard normal black basalt, which remains tolerably fresh, while the surrounding general body of the sheet has undergone decomposition.

The upper part of this sheet is highly amygdaloidal, the vesicles being sometimes drawn out parallel to the upper and under surfaces, and again seeming to bend round a spheroidal mass or clustered irregularly in the spheroid itself. The upper surface is rough and slaggy, with a few large amygdales of calcite. It is covered by another intercalation of

11. Black Shale (5 or 6 inches to less than one inch in thickness). This layer of sediment, marking another pause in the discharge of lava, is dull and earthy. It appears to have suffered a good deal from the action of the basalt above it, which occasionally descends and cuts it out entirely. Some of its layers are seamed by thin lenticular calcareous laminæ, with thicker partings of limestone that run parallel to the planes of bedding, but also ramify downwards into the earthy basalt below. When lava again began to flow over this ground it took the form of

12. Basalt, which now extends in a well-marked columnar sheet, from 12 or 15 to 25 feet thick, consisting of a compact, hard blue or black rock, containing grains of olivine.* It is sparingly amygdaloidal, though showing a few large cavities filled with calcite. Its columnar structure is more distinctly perceived from a little distance, when the characteristic dull, brownish colour of the rock contrasts well with the pale-green of the earthy amygdaloids below and above. Its under surface is irregular, corresponding partly to the inequalities of the dull green lava over which it flowed, but partly also belonging to itself, for it cuts out portions of the underlying shale, and sometimes rests directly on the amygdaloid. The portions of the rock near the bottom lose their hard compact texture, become dull, greenish, earthy, and weather into rough spheroidal masses, which in these respects closely resemble the earthy sheets already described. This change sometimes extends upward for more than a foot, but in other places not more than two or three inches. The upper surface of the basalt presents a

* Boué describes this rock as "une couche épaisse d'un basalte noirâtre à structure columnaire, prismatique, si distincte qu'on croirait être sur un pavé basaltique du Vivarais." Essai, p. 473.

remarkably rough and scoriaceous aspect, knobs of irregular and even fantastic forms extending upwards into and being enveloped in the lower part of the overlying sheet (Fig. 9). The bottom of

FIG. 9.—Solid black basalt with its rugged upper surface overlain by "earthy basalt," east of King Alexander's Crag, Burntisland.

the sheet also presents a repetition of the frequent association of the hard black basalt, intermingled with the dull earthy green variety.

13. EARTHY BASALT, dull, highly amygdaloidal, of a light greenish grey colour, and strongly calcareous, calcite showing both in kernels and veins. This sheet is the roughest and most slag-like mass in the whole cliff. The scoriaceous aspect of its upper surface is truly remarkable, while the whole rock, even the harder portions of it, is strongly vesicular. From its light green colour it forms a marked zone along the cliffs, when seen from a distance. Above it an interesting intercalation of sedimentary layers marks a somewhat more prolonged interval of quiescence in the volcanic activity.

14. SHALY AND OTHER SEDIMENTS, forming an intercalation about 12 feet thick, composed of the following strata in ascending order :—

Black carbonaceous shale, almost a coal in places, forming an inconstant seam on the surface of No. 13.

Brown, shaly fireclay, about 5 inches thick, full of rootlets ; covered by

Coal, about 5 or 6 inches, some of its laminæ being good bituminous coal, while others are brown and earthy and pass into shale.

Fireclay, green, ashy, and crumbling, about 12 inches thick ; full of rootlets. In the year 1864 an extremely interesting occurrence was visible in this bed.* An angular block of a pale felspathic diabase or basalt, different from the lavas of the cliff, and about 9 or 10 lbs. in weight, was observed to be imbedded in the fireclay, the layers of which, for an inch or two from the bottom of the bed, were bent down on either side of the stone, while the coal below was also compressed (Fig. 10). The fireclay was heaped up round the upper part of the stone until it was covered, when the layers of sediment ran on in unbroken horizontality. This stone was evidently an ejected block shot from some neighbouring vent at the time when a muddy deposit, no doubt partly due to the discharge of volcanic dust, was gathering over a

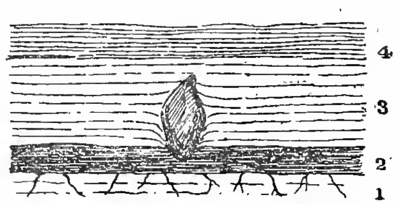


FIG. 10.—Volcanic Block ejected during the deposition of a group of sedimentary strata among the Burntisland lavas.

1. Brown shaly fireclay with rootlets. 2. Impure coal. 3. Green ashy fireclay, the lower layers pressed down by the stone, while the upper layers rise over it. 4. Green and black ashy shale.

* Geo. Mag., Vol. I., p. 22.

submerged sheet of still soft vegetation. When it fell it sank into the yielding silt, which was depressed by its weight. But the same kind of deposit continued after the fall of the stone, which was finally entombed under the latest layers of silt.

Dark greenish and black shale, with plants, &c. (about 6 inches), passing into the fireclay below.

Green ashy shale (about 3½ feet). Some parts are fine and marly, like the "Houston marls" of West Lothian; others contain coarser volcanic detritus, and pass into a fine marly tuff. The seam includes also bands of ordinary blue shale without any marked admixture of ashy material. Cyprids and fragments of plants abound in some of the layers.

Green ashy sandstone (6 inches), full of brown and black plant-stems and cyprid cases, with small specks of coal.

Green ashy shale (14 inches), with brown plants and coprolites. Some bands of fine tuff are intercalated in the deposit, while the lower part consists of blue and fissile shale.

Blue shale (about 18 inches), full of cyprids and fragmentary plants, together with fish-remains. Some interstratified bands of cyprid limestone consist of little else than entomostracan valves, mingled with a little argillaceous matter, streaks of coal, and carbonised plants.

Green shales, 4 feet thick, including a band of coarse argillaceous limestone, 2 inches thick, close to the top at one part of the section. These shales contain some bands of sandy green tuff. Their green colour and felspathic composition are no doubt mainly due to the quantity of volcanic dust which they contain. Cyprids and plant-fragments abound in some of the bands.

15. Basalt (about 15 feet), rough, scoriaceous, and earthy on the top, the central portion being compact, fine-grained, of a blackish-blue colour, with visible grains of olivine, while towards the base the rock again becomes earthy, of a dirty brown colour, and strongly amygdaloidal. The amygdales (chiefly calcite) are for the most part small; yet a few also occur of larger size, oblong, an inch or two in length, and $\frac{1}{8}$th to half-an-inch broad. These are chiefly remarkable for being drawn out eastwards and sloping up in that direction from the base of the bed at various angles from positions nearly parallel to the plane of bedding up to 45° or even more. So abundantly vesicular and amygdaloidal is the whole mass that it must have rolled along as a stream of open, highly porous and cavernous slag. From the fact of the elongation of the vesicles we may infer that the lava moved in an easterly direction. The crater of eruption may therefore be supposed to have lain to the westward. There are indeed other reasons for believing that one of the main vents lay either on the site of The Binn or somewhere in its near neighbourhood.

At the east end of the cliff of Kingswood End some stratified seams appear which are not seen to the west. They consist of

16. Black and grey Shales lying immediately above the last basalt and close to the summit of the precipitous cliff at the east end of King Alexander's Crag. Their thickness cannot be precisely ascertained.

A few yards from the edge of the cliff some green earthy stratified tuff makes its appearance, containing rounded and sub-angular fragments of basalt, limestone, shale, and sandstone. The relations of this tuff will be immediately noticed. The next member of the series here visible consists of sandstone, partially seen in an old quarry and apparently only a few feet in thickness. These

strata pass under another great group of lavas. But before following further the upward volcanic succession we may pause to consider some interesting particulars connected with the tuff just referred to.

When looked at from a distance, as from the low-water edge of the beach or from the sea, the escarpment of King Alexander's Crag, with its prominent ribs of basalt, is seen to end off rather abruptly towards the east, and to be replaced by a slope of blown sand covered with grass. A closer inspection shows this truncation to be not less complete in reality than in appearance. The ends of the sheets of basalt, as well as of their intercalated shales, are cut off nearly vertically and are wrapped round by a mass of coarse agglomerate, consisting of a dull, earthy, greenish paste, in which are embedded blocks of basalt, shale, limestone and sandstone, of all sizes up to masses a yard or more in width. There is no trace of stratification in this rock, the oblong blocks being in many cases stuck upright in the matrix. The vertical margin of the agglomerate can hardly have been determined by a line of fault, seeing that the sheets which overlie the tuff and form the upper part of the hill are not displaced, and the peculiar pale, earthy basalt that overlies the columnar basalt of the crag is prolonged at its proper level on the east side. These appearances point to the existence here of a vent, in which the agglomerate consolidated, and from which the overlying tuff was probably ejected. The tuff consists of finer material than the agglomerate, and has been spread out in a stratified manner around the vent. The two materials, however, pass into each other. It would thus seem that while coarser detritus fell back into the vent and finally accumulated there as a tumultuous unstratified mass, that which was thrown further and settled down on the surrounding lagoon-bottom was there assorted into layers previous to the deposition of the sandstone above it and to the eruption of the sheets of lava that supervene. The lower basalts which have been blown out by the explosions that produced the vent are less compact at the edge of the vent than they are a little distance away from it, and they, as well as all the adjacent rocks, as so often happens in such circumstances, are bent down at a tolerably sharp angle towards the vent.

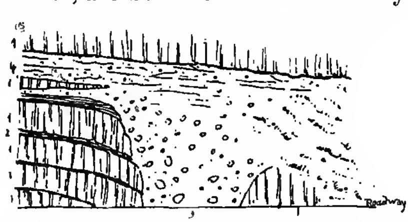


FIG. 11.—Section of Vent filled with agglomerate, east end of King Alexander's Crag, Burntisland.

1. Basalt lavas. 2. Black shales, thin tuffs and seams of cyprid limestone. 3. Agglomerate of the vent. 4. Stratified tuffs.

On the east side of the agglomerate, the basalt which overlies the ashy shales and limestones above described is seen on the roadside, with its characteristic hard, black centre, and rough, green scoriaceous top. It is truncated abruptly by the agglomerate, the hade being to the west at a high angle, and here we have the other side of the vent.

At this part of the coast we must leave the hill-slopes and inland escarpments, which now descend to the beach, where they present a continuous and clear series of sections, both in shore-cliffs and in reefs between tide-marks. It should be mentioned that here a gentle synclinal fold of the rocks, clearly visible from a distance at sea, prolongs the same sheets which have now been described, so that for perhaps half a mile we do not reach any higher horizon. The most westerly rocks that rise from the beach in a range of picturesque crags are a continuation of the lower basalts above described. But they display still better some of the characteristics of these lavas. The earthy varieties are often quite slaggy. They exhibit also the ellipsoidal structure already referred to, examples of which will repeatedly occur in the following description of the coast-section further to the east. This well-marked "pillow-structure" appears to indicate that, while still moving as molten masses, they separated into irregularly ovoid, sack-like, or pillow-shaped blocks of all sizes, from less than a foot to 5 or 6 feet in length. (See Fig. 13.) These blocks are frequently most cellular in the centre, the vesicles being there largest in size and most crowded together. In other cases, the vesicles are grouped around the margin and sometimes more particularly along one side of each ellipsoid. In the interstices between the blocks fine tuff or ashy sandstone may sometimes be seen, showing that the rude boulder-like masses were more or less separated from each other, so as to allow fine sediment to be dropped into the interspaces. This sediment is stratified horizontally, or in the same direction as the general bedding-plane of the lava in which it lies. Other varieties of this structure will be noticed in the sequel.

As they rolled along over the lagoons and pools of the time, the basalts, now exposed on the shore west of Pettycur, caught up and involved large quantities of the muddy and calcareous sediments which lay in their way. On the shore at the base of the cliffs lie numerous blocks of a pale limestone, which may have fallen out of these basalts. They have been derived from a bed apparently about two or three feet thick, and probably of local and lenticular development. This limestone band has not been met with *in situ* in the district. It is especially distinguished by the number and exquisite preservation of the plants which it encloses. It probably accumulated in some pool, into which the vegetation of the surrounding ground was blown or washed, in an interval of volcanic quiescence. Attention was first called to the remarkable perfection of the fossils of this limestone by the late Mr. Grieve, who supplied specimens of them to the late Professor Williamson. Several of them were described in the Professor's monograph "On the Organisation of the Fossil Plants of the Coal-measures."* Further research into the structure of these organisms is at present being carried on by Mr. R. Kidston and Dr. Scott. Mr. Kidston

* Published in Phil. Trans., Vols. 162–186 (1877 to 1896).

has meanwhile been kind enough to furnish the following provisional list of the species hitherto obtained:—

Rachiopteris duplex, Will.
Rachiopteris (allied to R. Oldhamium).
Rachiopteris, sp.
Annulate fern-sporangia.
Heterangium Grievii, Will.
Lyginodendron, sp.
Bornia.
Lepidodendron brevifolium, Will. (not Ett.)
Lepidophloios scoticus, Kidston.
Stigmaria.
Cheirostrobus Pettycurensis, Scott.
Lepidocarpon.

Some further interesting features in the structure of the Carboniferous lavas are well exposed on this part of the beach. The cellular character of some of the basalts is largely developed and presents here some peculiarities. In a few of the sheets the crowded vesicles have been elongated and arranged vertically, like rows of worm-burrows, and, as they are filled with white calcite, their contrast with the dark ground of the basalt makes them conspicuous. They stop short at the top of their own sheet and are directly overlain by the next compact blue basalt.

The last tuff referred to in the description of the continuation of King Alexander's Crag as being lost under the sandy and grassy slope may possibly lie on or about the same horizon as some shales and limestones exposed in the railway cutting to be immediately described. But it should be understood that, throughout this volcanic series, both the lavas and the interstratified tuffs and other sediments are remarkably inconstant and local in their extension. Even from where they attain an unusual thickness, they may be found to die out rapidly.

17. Shales and Limestone bands (8 or 10 feet in the railway cutting), grey, fissile, and full of cyprids and plants. Like the thick limestone of Burntisland, these bands, in their lithological character and fossil contents, closely resemble the typical limestone of Burdiehouse. They occur in balls, in lenticular seams, and in more continuous bands, one of which is about 4 feet thick. The material is yellowish, finely stratified, in layers of lighter and darker colour. This band of strata, as displayed in the cutting, is immediately overlain by a rough scoriform basalt, and this again, close to the tunnel, by some higher bands of cyprid limestone, the upper part of which is concealed by the grass of the embankment.

Let us now take up the continuous shore-section from the harbour of Pettycur eastwards to where the Hurlet Limestone closes the Burdiehouse Limestone group on the beach at Seafield. The lowest lava of the railway cutting is a dull, green, earthy vesicular basalt, enclosing and passing into masses of hard black, sometimes rudely columnar, basalt. Nowhere is the intimate mixture of the two phases of these lavas better displayed than here.

When the band of shale and limestone (No. 17) which overlies this basalt in the cutting is followed southwards, it is seen to undergo rapid lithological change. The limestones thin away and give place to greenish sandy and ashy shale, black shale, and shaly sandstone, with remains of *Sphenopteris*, &c. A sheet of basalt 8 feet thick intervenes in the middle of the band, but rapidly dies out northward. At a part of its course the sedimentary band is completely cut out by the coming together of the basalt below with that above (No. 18).

18. BASALT, resembling that below the shales and limestones in the commingling of dull, greenish, earthy amygdaloidal portions with others in which the rock is comparatively compact and fresh. This lava as it rolled over the bottom of the water appears to have caught up much shale and ironstone and to have carried along these foreign materials embedded in its mass. In some of the enclosed ironstone balls the coprolitic enclosures are still well preserved. On one part of the cliff by the roadside, east from the harbour, the quantity of involved shale is so great as to constitute nearly half of the basalt. The whole sheet is vesicular, while some parts are scoriaceous or almost brecciform—a structure especially prominent towards the top, where the shale fragments, together with balls of coarse limestone and ironstone, become exceedingly abundant. Here and there amid the multitude of included fragments detached pieces of *Lepidodendron*-stems appear embedded in the igneous rock.

In this lava the ellipsoidal structure is well marked, and the interstices between the blocks are in some cases filled in with ironstone which has either come in from above before the next lava was poured out, or, what is more improbable, was soft enough when ploughed up from the bottom of the water to mould itself to the shape of the interstices between the lava-blocks. Here again the large size and crowding of the steam-vesicles in the centre of the ellipsoids is conspicuous. These cavities have been first lined with crystals of calcite and then filled in with a fibrous form of the same mineral.

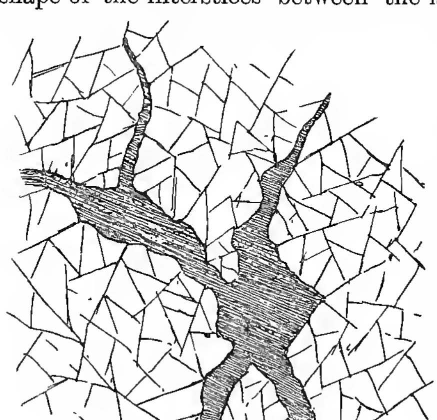


FIG. 12.—Section showing ramifying veins of finely stratified tuff, from less than a line to a foot or more in width, filling up the interstices of a basalt lava. Pettycur.

19. BASALT, dull brownish-green or dirty-black, full of calcite amygdales and veins, and arranged in harder and softer bands which, like the general succession of rocks here, dip eastward at 20° or 25°. It is surmounted by

20. BASALT (3 to 6 feet), hard, blue, fine-grained,

full of olivine. In this sheet the interstices between the "pillows" have been sometimes filled in with chert.

21. BASALT (20 feet), like the bed below, but consisting partly of strongly amygdaloidal or slaggy portions, enclosing solid blue fresh masses. In some of the interstices in the slaggy parts of this sheet, ironstone has been deposited; into others an extremely fine volcanic silt has made its way and filled them up. This material has been laid down in thin layers, which extend from side to side of the crevices, and lie in the same plane as the general bedding of the surrounding rocks (Fig. 12.)

22. GREEN TUFF (12 feet), fine-grained and well stratified. On the shore the lower part of this ash becomes very shaly, and contains one band of black carbonaceous shale, which, however, may be the same as part of No. 23.

23. BLACK SHALE, COAL, AND FIRECLAY, arranged in the following order, immediately above the green tuff (No. 22) and below No. 24:—

Black shale	6 inches.
Coal (splint)	3 ,,
Dark fireclay	6 ,,
Coal	6 ,,
Dark fireclay	12 ,,
Coal (splint)	10 ,,
Fireclay, resting on No. 22	4 ,,

This alternation of old soils and terrestrial vegetation marks an episode of quiescence between the showers of fine volcanic ashes represented by Nos. 22 and 24.

24. GREEN SANDY TUFF, with limestone and shale, fine-grained and well stratified (total thickness not seen), coarsest in texture towards the top, where it contains small basic lapilli and blocks or bombs of highly vesicular basalt. The shore-section of this band in front of the old inn admirably exhibits its alternation of coarser and finer layers, the fine-grained character of the whole, the alternation of calcareous and argillaceous with the volcanic sediments, and the absence of stones. The following section displays the remarkable alternation of volcanic and sedimentary conditions recorded by the band, in a thickness of less than two feet of deposit:—

Tuff	1·5 inch.
Limestone	0·2 ,,
Tuff	0·5 ,,
Shale	0·2 ,,
Tuff	0·1 ,,
Shale and tuff	1·0 ,,
Shale	0·2 ,,
Limestone	0·5 ,,
Shale full of volcanic dust	3·5 ,,
Shaly limestone	1·5 ,,
Laminated tuffaceous limestone	2·0 ,,
Limestone in thin bands, with thin laminæ of tuff	0·8 ,,
Granular tuff	0·6 ,,
Argillaceous limestone, with diffused tuff ...	0·9 ,,
Fine granular tuff	0·7 ,,

Argillaceous limestone, with diffused tuff ...	1·5 inch.
Laminated limestone	0·1 ,,
Limestone, with parting of granular tuff in middle	0·9 ,,
Tuffaceous shale	2·0 ,,
Limestone	0·4 ,,
Shaly tuff	1·25 ,,
Laminated limestone	0·1 ,,
Tuff	1·2 ,,
	21·65 inches.

25. Basalt (12 to 16 feet) lying irregularly on the tuff (No. 24) and partly cutting it out. The lower portion of this rock is firm and compact, with small vesicles. Further up it becomes more solid and less vesicular, passing into a hard black basalt, with abundant olivine. The upper part, rough, earthy, and brecciform, has the usual greenish hue.

26. Black Shale and fine Tuff, with fragmentary plants (about 3 feet), covered by

27. Basalt (about 30 feet), the most beautiful lava of all this volcanic series. Its base, which rests not very unevenly on the shales (No. 26), is for three or four inches upwards broken, or brecciform, with the usual earthy texture and dirty-green colour. It then becomes firm and compact, though still remaining of a greenish hue, but slowly shades up into its prevailing character of a dark, hard, flinty, regularly columnar basalt, with olivine. The columns reach to within a foot of the bottom of the bed and are often perfectly symmetrical, their hexagonal prisms rising up along the face of the cliff or exposed as a rough tesselated pavement on the shore. They are liable, however, to sudden cessation. At a part of the cliff close to the east end of the old inn a portion of the bed, with its regular columns, is sharply cut off by an overlying mass of amorphous basalt, which in its progress laterally becomes itself columnar, and then the pillars of the lower sheet are continuous through the united mass to the top of the cliff. Though not perfectly straight, but rather curved and slightly sinuous, the columns show none of that confused assortment at different angles which characterises the basalt of King Alexander's Crag. Towards the top of the bed the columns cease, and for the upper 10 or 20 feet the rock is massive, weathering on the shore into rude spheroids, with a good many vesicles, which are drawn out parallel to the plane of the bed in a north and south direction. The upper surface of the sheet, which assumes the same pale-green and earthy texture as the bottom, is somewhat rough and uneven, and passes under

28. Black Shales (12 to 14 feet), with plants, becoming green and ashy towards the top. These shales are surmounted by a band of

29. Coarse green sandy and ashy Limestone (irregularly one foot), covered by a few inches of

30. Green Shale like that below the limestone. This is overlain by another

31. BASALT. Upwards from the bottom, for from six to twelve inches, this sheet is rough, green, and earthy. It then passes into a firm, dark crystalline rock, while towards the top it assumes the same slaggy aspect as at the bottom. It passes under another

32. BASALT, firm and compact, like the last. Above this bed a space of 15 or 20 feet occurs on the shore covered by sand and boulders. But some fine tuff can be detected at one part of the gap.

33. BASALT, very slaggy below, as seen on the shore, becoming firm and solid higher up. It is covered by a further

34. BASALT, strongly slaggy, for some yards from the bottom. Its central part is firmer, darker, and fresher, but towards the top the usual rough texture, greenish tint, and more decomposed character of the parts next the cooling surfaces, are resumed, and the rock becomes similar to the peculiar earthy basalts of King Alexander's Crag. This sheet is of considerable thickness. It is covered by

35. TUFFACEOUS SANDSTONE AND SHALE (6 or 8 feet), green and fine-grained, without included stones, possibly a continuation of some red and green shale seen below a basalt near the eastern entrance of the railway tunnel.

36. BASALT (fully 30 feet). Its upper part has a highly earthy and amygdaloidal texture, some of the vesicles being large and filled with quartz or with calcite. There may be more than one flow here, as is suggested by the fine ashy sediment that has filled in the sutures between the huge "pillows" on the beach.

37. GREEN TUFFACEOUS SHALE, with bands of fine green tuff (about 7 or 8 feet), dipping easterly at 33°. The lower beds consist of a kind of gravelly tuff, with large bombs in the lower part. Those in the middle are more argillaceous, but with still a considerable intermixture of volcanic dust, whilst for a foot or two from the top they again become ashy, forming a kind of sandy tuff. Even in the finest bands of this intercalation there occur occasional angular and subangular lapilli and larger blocks of finely vesicular slag.

38. BASALT. The under part of this lava is very brecciform and scoriaceous. Its vesicles are drawn out round irregular masses more solid, fresh, and black than the surrounding parts.

39. BASALT, with a most irregular bottom, corresponding to the uneven top of the underlying sheet (No. 38). This is one of the most compact lavas of the whole series. It consists of a dark black fine-grained basalt, remarkably fresh and hard, and showing on its weathered surface a spotted character that suggests a variolitic internal arrangement, which, however, has not been recognised under the microscope. It is a rock of the Dalmeny type, and has been studied by Mr. H. J. Seymour, who finds that "the ground-mass contains abundant augite in small crystals, which show a tendency to idiomorphism. The plagioclase laths associated with the augite present a more or less marked flow-orientation. The porphyritic constituents are olivine and augite, the former being most abundant

in well-formed crystals, which occasionally attain a length of 2 millimetres. They are mostly altered to greenish and yellowish-brown serpentinous material. Augite is less conspicuous as phenocrysts. The rock contains a little residual glass."

This basalt is not columnar, but is abundantly traversed by joints or divisional planes, which, though parallel, on the whole, to the planes of cooling, frequently coalesce, and thus give rise to large lenticular beds or cakes. The lower black jointed part of the sheet is fully 30 feet thick. The higher portion, about 8 or 10 feet, is freckled with red, owing to the decomposition of some of the ferro-magnesian constituents, and passes up into a mass of the usual scoriform character.

40. Brick-red Clay or Bole, of which only a few inches are seen below the next lava. This intercalated layer is cut off by basalt before it ascends the beach to high water-mark; but its disappearance may be due to a small fault.

41. Basalt, firm and compact in the lower half, the rest being dull green, earthy, scoriaceous, and amygdaloidal.

41a. Coarse Tuff or Agglomerate, greenish in colour, made up of finely cellular lapilli or pumice, as so many of the tuffs are, and showing the pumiceous character with marked distinctness. The material becomes finer in grain above, passing upwards into a red bole-like substance.

42. Basalt (14 or 15 feet), strongly amygdaloidal throughout, but especially towards the top and bottom. It contains some curious bands like intruded veins of a finer and more minutely amygdaloidal texture than the main mass, which is distinctly crystalline in texture. Some calcite veins or partings run in parallel layers in a line with the dip of the mass and tend to give the whole a bedded aspect. The sheet occupies the lower part of the prominent crag or headland called Kinghorn Ness.

43. Basalt (at least 40 feet), very compact, hard, and crystalline, weathering with a rich reddish-brown surface and running out to sea as the promontory of Kinghorn Ness. The weathered surface with its small empty vesicles strikingly recalls the finely carious or minutely cellular structure of many Tertiary lavas, such as the older coulées of Auvergne. The under portion of the sheet presents the usual scoriaceous and amygdaloidal structure, but the rest of it is for the most part a compact, solid basalt. Its line of demarcation from the next basalt is not clearly marked, and there may be some doubt whether the small creek immediately under the garden of Rossness House should be regarded as having been excavated between two basalts or only in the mass of the rock just described. In the latter case the sheet would be 70 or 80 feet thick. This more easterly basalt, whether regarded as a separate flow or as an upper part of No. 43, is admirably exposed along the coast, which here bends round to the north so as to correspond with the strike of the beds. The basalt, in rough scoriaceous masses that occasionally look like coarse volcanic agglomerate, forms a steep irregular cliff and a series of craggy

rocks along the shore. In no part of this coast-section can some of the distinctive features of these basaltic lavas be so easily studied as in this sheet. The "pillow structure" is well displayed. The accompanying diagram represents a surface of the sheet about 12 feet wide by 10 feet high. Some of the blocks are four or five feet long. Their abundant, and often large, amygdales consist mostly of calcite, but sometimes of zeolites. The interstices between the blocks are in some places filled mainly with calcite; in others with chalcedony, or with fine green stratified tuff, having its laminæ parallel to the dip of the sheet. But here and there the infilling material has been a close-grained basalt, which has been subsequently minutely intersected with threads of calcite. Like the bands that occur in the lava No. 42, these ramifying basalt veins may perhaps represent portions of the still molten rock which, as the mass moved on, were injected into the fissures between the already congealed ellipsoids.

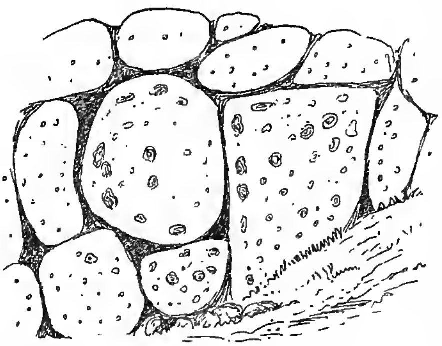


FIG. 13.—Ellipsoidal Basalt ("pillow-structure"), west side of Kinghorn Bay.

But the most singular characteristic of the basalt now described is the abundance of the included foreign fragments. These consist of vitreous quartz, vitrified quartzite or grit, chert, jasper, and other rocks. Most of the stones are angular. Many of them are evidently portions of sandstone seams. But among them are not a few well-rounded pebbles of quartz, which have manifestly been derived from some conglomerate. All of them have undergone intense induration, the quartzite being vitrified into a glass-like substance, the limestone changed into marble, while through some of the finer siliceous pebbles run threads of basic igneous rock, which seem to incorporate and shade off into the surrounding stone.

This metamorphism appears to be much greater than would be likely to be superinduced upon fragments of rock or pebbles caught up by a cooling lava as it rolled over the bottom of the water. Moreover, there are no known conglomerates in any part of the Burdiehouse Limestone group of this neighbourhood that might have lain at the surface as loose shingle when this basalt was erupted. More probably the included stones were borne up by the ascending lava-column from a considerable depth and were immersed for a long time in a bath of thoroughly liquid rock. The large well-rounded and smoothed pebbles of quartz resemble those of the conglomerates of the Lower Old Red Sandstone. If

they came from that source they must have been carried upward from a depth of several thousand feet. They seem to have been detached from a particular part of the volcanic funnel, for they are chiefly found along a band not far from the top of the basalt, where they are crowded together in patches.

43A. GREEN ASHY SHALE AND TUFF. Above the interesting basalt just described lies an inconstant band of green shale and fine tuff. In some places it is two feet thick, but quickly dies out, to come in again on the same horizon further along the shore. Here and there the tuff is full of vesicular bombs and smaller lapilli.

44. BASALT, a black, solid, compact rock in large irregular columns. Its bottom, for about a foot or so upward, presents the characteristic broken, dull, earthy, and amygdaloidal structure. This prominent sheet forms the crag called the Carlinhead Rocks, on the west side of Kinghorn Bay, and is seen in detached outliers along the beach towards the north resting on the shale and basalt below.

A sandy bay now intervenes forming the harbour of Kinghorn. It has been hollowed out of a softer series of rocks.

45. SANDSTONES AND SHALES (about 200 feet). This thick intercalation of sedimentary material marks a prolonged interval of volcanic quiescence, when the floor of the lagoon-waters continued to sink and to receive deposits of sand and mud from some neighbouring land. These strata are full of remains of terrestrial vegetation. Near their top a seam of "gannister," or hard quartzose sandstone, may be noticed to be crowded with *Stigmaria.*

46. BASALT. This sheet, representing the renewal of volcanic activity in the district, forms a reef which runs out to sea on the north-east side of Kinghorn Bay. Dark, solid, and amygdaloidal, it mainly differs from the basalts already described in possessing a more coarsely crystalline or doleritic texture. But it is obviously a true lava. The same texture recurs frequently among the sheets to the east of this point. From the time of this Kinghorn basalt onward a change must have taken place in the condition of some part of the magma which supplied the lavas.

47. GREEN TUFFACEOUS SHALE OR MARL (1 foot), like that of the Carlinhead Rocks. It passes beneath

48. BASALT, distinguished by a reversal of the usual arrangement of parts, for its centre is highly amygdaloidal, while the bottom and top are compact. There may, however, be three beds, two firm and close-grained, separated by one of an opener and more cellular texture.

49. SANDSTONE AND SHALES, with plants (about 25 feet).

50. EARTHY BASALT,* pale green, amygdaloidal.

51. QUARTZITE†, or hard white sandstone. This band is inconstant,

* Boué calls it "une amygdaloïde à base de wacké." Essai, p. 475.

† The occurrence of quartzite among the basalts of this coast-section attracted attention during the famous controversy between the Neptunists and Plutonists a century ago. MacCulloch, in his paper on Quartz-rock (*Trans. Geol. Soc.*, Vol. II. 1814, p. 455), remarked that "neither is the perfect crystalline texture of quartz any proof of a primitive formation; since the strata of Kirkcaldy, which belong to the Flœtz and Coal

for, while sometimes three or four feet thick, it thins away towards the north and thereafter thickens again below the cliff. Owing to the denuding action of the sea the basalt below this bed has been worn into peaks and bosses, several of which have outliers of the quartzite resting upon them. This quartzite lies unevenly on the basalt below, some parts of it being wanting altogether.

52. BASALTS. The beach for a space of fully 300 yards is now occupied by a series of igneous rocks which are not easily separable into distinct bands, though they may reach a total thickness some 300 feet. At their base lies a basalt with a highly amygdaloidal bottom which rests on No. 51. This band forms the Abden Rocks to the east of Kinghorn. Further east, partings of sandstone and quartzite serve to separate some of the igneous masses, which may possibly include one or two sills. Among the bands, some are of a markedly basic or picrite type, in which porphyritic olivine is more common than augite, and appears in a groundmass of augite granules set among lath-like felspars.

Above this thick mass of erupted material we next come upon

53. FISSILE SANDY SHALE (12 or 14 feet) ripple-marked, light-grey, and enclosing plants.

54. BASALT (8 or 9 feet), vesicular and amygdaloidal at bottom and top, more close-grained in the centre. The lower and the upper surface of this sheet pass into a parting or layer of red and green clay or bole, such as is so commonly to be observed in this coast-section. That this substance must sometimes at least arise from the decomposition of the lava *in situ*, seems to be indicated by the fact that the disseminated crystals and amygdales of the present basalt occur, as if in their natural positions, in the red seam overlying it. The appearances here, as well as at the Carlinhead Rocks and other parts of the coast-line, suggest that certain basalts underwent a peculiar modification along the contact of their bottom with the sediments over which they flowed. No connection has been traced between the occurrence of the bole and any particular kind of pavement, for the layer sometimes occurs on one kind of sediment, sometimes on another, and even between two sheets of basalt. Possibly the modification may be due to some special peculiarity in the composition or behaviour of certain lavas as they rolled along the sea-floor.* At the top of this basalt an inconstant parting of fine tuff separates it from the more solid sheet above it.

55. BASALT, highly amygdaloidal for a foot or two from the bottom, when it passes into a dark, compact, solid rock, here and

formation, contain beds of highly crystalline and translucent quartz, alternating with coal and organic limestones." Boué would not admit that the rock owed its present texture to the induration caused by eruptive rocks. He speaks of "un grès compacte, faussement qualifié de grès endurci par les sectateurs de Hutton." Essai, p. 475. In judging of the effects of the igneous rocks on the sandstones, we should take note of the fact that some of these strata are gannisters or exceedingly hard siliceous sandstones, which owe nothing to induration by igneous rocks, as in the group of strata No. 45.

* Boué, describing bands 54 and 55 as "une amygdaloïde à base de wacké," remarks that this amygdaloid contains "un lit peu épais d'une substance brune rougeâtre approchant de la nature de la wacké et contenant de très petits noyaux de la même nature que la base." Essai, p. 475.

there rudely columnar. This sheet shows well the passage of irregular masses of hard blue basalt into the soft, dull, earthy, scoriform condition. The top becomes dull, green, earthy, and amygdaloidal. Here and there the steam-vesicles of this sheet are as much as two feet long. These are sometimes merely lined with calcite crystals, sometimes entirely filled with that mineral, which can be extracted in large milky-white rhombohedra.

In this basalt we again meet with evidence of the intrusion of other basalt. Veins of a fine green minutely vesicular basalt have been injected in the same way as those in Sheet 43. The vesicles are filled with soft green decomposition products. As already suggested, it seems most probable that such veins represent some portions of the sheet which were the last to solidify, and which were forced into the crevices between the already solid "pillows."

Reference has already been made to the occurrence of bands of limestone containing marine fossils on various horizons in the Burdiehouse Limestone group. These bands show that, though the estuarine conditions of sedimentation prevailed during the accumulation of the group, as shown by the abundant land-plants, the occasional seams of coal and oil-shale, the cyprid-limestones and shales, and the distinctive fish-fauna, there were occasional intervals during which the waters of the opener sea made incursions into the lagoons or estuary, and carried thither another type of organisms. We are now arrived at some of the more interesting platforms in the coast-section where this intercalation of marine life is presented. The Abden shore presents a succession of shales and limestones containing the same fossils as are found in the Hurlet Limestone, which, for the reason already assigned, is taken as the base of the Carboniferous Limestone series. It will here be seen that the conditions under which the Hurlet seam was accumulated had already arisen in the higher part of the Calciferous Sandstone series.

56. Dark Shales (3 feet). Near the base of this band lies a "bone-bed," an inch thick, which has yielded numerous remains of fishes, including *Eurynotus crenatus*, *Elonichthys pectinatus*, and remains of *Cœlacanthus*, *Megalichthys*, *Rhizodopsis*, &c. Higher up comes a band (*Myalina*-bed), from which Mr. James Bennie obtained *Naiadites* (*Myalina*) *crassa*, *Naiadites*, large sp., *Aviculopecten ornatus*, *Pteronites persulcatus*, *Sanguinolites abdenensis*. The same observer detected higher up another marine band (*Pecten*-bed), containing *Lingula squamiformis*, *Aviculopecten ornatus*, *Myalina sublamellosa*, and some of the same species of shells as were found in the band below. Throughout the dark shales remains of plants occur, including *Calymmatotheca* (*Sphenopteris*) *affinis* and also fragments of scorpion.

57. Soft pale marly Shale or Fireclay (18 inches), with fragmentary plants.

58. Dark Shale (18 inches). This thin band has furnished a large number of fossils, including species of *Endothyra*, *Stacheia*, *Valvulina*, *Bairdia*, *Beyrichia*, *Leperditia*, *Lingula*, *Productus*

Aviculopecten, *Edmondia*, *Myalina*, *Pteronites*, *Sanguinolites*, *Aclisina*, *Murchisonia*, *Conularia*, *Orthoceras*, &c. The upper surface of the bed is crowded with *Productus* and other shells in a fragmentary condition. The fossils have obviously undergone a good deal of movement in the water, such detachable portions as the spines of *Productus* lying scattered about.

These bands of black shale (Nos. 56 and 58), in affording the first indication of thoroughly marine conditions which has occurred throughout our traverse of the volcanic pile, clearly indicate that the physical geography of the district was now undergoing considerable change. The lagoon phase, so long continued, began to give place to inroads of the clearer and more open sea beyond. But the volcanic energy, though drawing to a close, was not yet exhausted, as the overlying strata show.

59. GREEN AND RED TUFFS (6 feet) in bands of varying texture, but generally exceedingly fine. The same strata are also exposed in the railway cutting. They indicate a prolonged discharge of the lightest volcanic ashes. Some hard calcareous bands at the top mark the beginning of the sedimentary conditions under which the overlying limestone (No. 61) was deposited.

60. SHALE (1 foot), with nodules of limestone largely composed of aggregated crinoid-stems. This thin bed has yielded a large number of species of marine organisms. (See Appendix, p. 240.) Among these are various forms of *Endothyra*, *Valvulina*, and *Bairdia*, together with species of *Archæodiscus*, *Climacammina*, *Chonetes*, *Orthis*, *Spirifera*, *Archæocidaris*, &c.

It will be observed that the bands of marine limestone generally lie on a pavement of blue calcareous shale, in which some of the fossils found in them are already present. The cessation of the transport and deposit of mud allowed these organisms to flourish more abundantly, and as the water cleared they were enabled by the aggregation of their remains to build a layer of limestone upon the sea-bottom.

61. LIMESTONE (10 feet, 1st Abden Limestone) in several seams, of which the lowest is about three feet thick, separated by thin shaly partings. This is a characteristically marine limestone, full of corals, crinoids, brachiopods, &c. (See Appendix, p. 240.)

62. DARK CALCAREOUS SHALE (2 or 3 feet) passing up into dull green marl or fine tuff.

63. EARTHY BASALT, amygdaloidal throughout a large part of its course and presenting an irregular bottom, which has rolled over and caught up portions of the underlying shale and tuff.

64. TUFFACEOUS RED MARL and TUFF (3 or 4 feet). The lower part is a blotched grey agglomerate, made up of basalt-slags, wrapped in a paste of green tuff. The upper finer red portion is crowded with small pieces of finely cellular lava or pumice. Here both the tuff-matrix and the enclosed pieces of basalt have decomposed into red bole. These ferruginous layers have thus been derived both from lava and from pyroclastic material. They remind one of the bands of bole, lithomarge and bauxite among the Tertiary

basalts in Antrim and the Inner Hebrides, and also of the Indian laterites.

65. Basalt with a somewhat coarsely crystalline or doleritic texture, like that already noticed in the case of No. 46. That this sheet, however, is a true superficial lava and not an intrusive sill is abundantly evident from its structure. It is thoroughly slaggy and vesicular, and displays in great perfection the arrangement in pillow-shaped blocks, especially in the upper part. These ellipsoids are strongly amygdaloidal, and the interstices between them have been filled in from above with fine green and red tuff stratified parallel to the plane of dip of the sheet. This tuff, as usual, is made of a fine basic pumice. Calcite has likewise played its part in filling up the interspaces.

The change in the crystalline character of the lava already noticed under No. 46 now becomes more marked among the last sheets of the series. This feature, when the rocks are not so well exposed that their relation to the adjacent strata can be ascertained, sometimes makes the discrimination of sills from lava-flows a little difficult, though attentive examination will generally suffice to distinguish the sills by their more coarsely crystalline texture, their greater homogeneity, their close-grained texture at top and bottom next the surfaces of most rapid cooling, and the small size and comparative uniformity as well as rarity of their amygdaloidal cavities.

66. Red and green Marl or fine Tuff (20 feet). This deposit presents another good example of a rock formed by the discharge of fine volcanic ashes, and their settlement under water. It closely resembles the well-known "Houston Marls" of West Lothian, which had a similar origin. It rapidly thins away northward and is only some 6 feet thick in the railway cutting.

67. Dark Shales and Fireclay (8 or 10 feet). This zone consists of the following subdivisions in descending order :—

Soft blue shale (4 feet) containing corals, crinoids, entomostraca, *Discina*, *Lingula*, *Orthis*, *Productus*, *Streptorhynchus*, *Aviculopecten*, *Nucula*, *Macrochilina*.
Hard black shale (4 feet) containing some of the same fossils with species of *Myalina*, *Bellerophon*, and *Orthoceras*.
Thin parting (1 inch) containing *Myalina*.
Light fireclay (2 feet).

By increase of calcareous material the shale passes upward into the overlying limestone.

68. Limestone (about 14 feet, 2d Abden Limestone) composed of a number of separate bands, each from 6 inches to a foot in depth. One of the lower bands is full of *Lithostrotion irregulare*; above it comes another abounding in *L. junceum*. This limestone is also seen in the neighbouring railway cutting. (For list of fossils see Appendix, p. 240.)

69. Shales and reddened Sandstone, overlying the limestone and including a thin seam of coal. There may be 100 feet of these strata. They are invaded by two dolerite sills, by which the

contiguous sediments are much hardened. These two intrusive sheets are the lowest of a series which has been injected among the strata further to the east, and which will be again referred to in the account of the Kirkcaldy coal-field.

70. LIMESTONE (HURLET SEAM, altogether about 50 feet thick), seen on shore near Seafield Tower. At the base lies a carbonaceous black shale, with a thin parting of coal and an underlying fireclay, which may represent the coal so often found in this position throughout Scotland. This shale belongs to the non-marine or lagoon sedimentation. But it passes up into grey calcareous shale, with nodules of limestone, and abounding in fossils. Among these are *Zaphrentis*, *Productus longispinus*, *P. semireticulatus*, *Spirifera duplicicosta*, *S. trigonalis*, &c. The same organisms appear in the overlying limestone, which has been built out of their crowded remains. Thoroughly marine conditions were now for a considerable time established. The thick Hurlet Limestone points to a prolonged period of clear sea, when little sediment was carried from the land, and when the characteristic marine fauna of the Carboniferous Limestone was allowed to flourish unchecked.

Higher strata in the upward stratigraphical succession continue to crop out upon the beach beyond this limestone; but as we have now reached the top of the Calciferous Sandstone series, the further description of the coast-section will be deferred until we have to consider the Carboniferous Limestone (p. 91.) Before quitting, however, the consideration of the lavas and tuffs associated with the Burdiehouse Limestone group, we may take note of their distribution elsewhere than along the coast-section which has now been described.

In the interior of the country, though no continuous section can be found, the rocks appear in many places at the surface. The ridges within the limits of the volcanic area, as already stated, are generally formed by the hard basalts and dolerites, while the hollows between them, for the most part, mark the position of intercalated sedimentary bands (including tuffs), which, offering less resistance, have been more readily eroded by denudation. Unfortunately, a good deal of drift lies in these hollows, and this in large measure conceals what would probably be found to be the records of many interesting episodes in the volcanic history.

To the north-east of The Binn of Burntisland the lavas and tuffs extend from the coast for about three miles inland until they pass under the Hurlet Limestone at Invertiel. Their general disposition, their variations, and their rapid westward attenuation will be best understood from an inspection of the map. It will be noticed, for instance, that while on the shore the volcanic material immediately below the limestone is mainly basalt, with only a thin and inconstant band of tuff at the top, at Invertiel, little more than a mile inland, there must be from 250 to 300 feet of well-stratified tuff between the limestone and the lavas, as shown in the section in the Tiel Burn. Again, to the north and west of The Binn of Burntisland, a thick and extensive mass of tuff lies

immediately above the sandstones and limestones. In the eastern part of the volcanic district the tuffs play a quite subordinate part to the lavas, but to the west of The Binn they become the only representatives of the volcanic activity, for no true lavas have been observed there, though intrusive sheets are frequent enough. The most westerly tuffs in this district are those of St. David's, which for a third of a mile are so admirably displayed both in a cliff section and on the beach. It is difficult to fix precisely their stratigraphical position in the Burdiehouse Limestone group, as the limestone is not seen in that part of the district. They are well-bedded, and their component strata, though inclined on the whole to the west, have been thrown into a number of folds, sometimes with inclinations of 45°. Owing to these plications and a number of faults no satisfactory estimate can be formed of the thickness of this mass of tuff. It is probably not less than 300 or 400 feet.

This characteristic mass of pyroclastic material has the usual dull green colour, and contains abundant pale pumiceous lapilli and pieces of pale highly amygdaloidal basalt, varying in size up to blocks a foot in diameter, also fragments of sandstone and black shale, abundant pieces of an older fine-grained tuff, and occasional angular chips of coniferous wood, as at St. Magdalens, near Linlithgow. In many respects this rock recalls the characters of the material that often fills up the volcanic vents of the region, and to which further reference will immediately be made. The fragments of fine tuff in it suggest the disruption of the consolidated detritus round the sides or within the crater of a volcanic cone, and though the general bedded structure of the St. David's rock marks it out as probably a mass interstratified with the neighbouring sandstones and shales, it probably lies not far from the site of the actual vent from which its materials were discharged.

CHAPTER VII.

The Volcanic Development of the Burdiehouse Limestone Group —continued.

(ii.) VOLCANIC NECKS.

An interesting feature in the volcanic district of Burntisland is the occurrence of a number of the vents from which the lavas and ashes described above were probably ejected. The actual chimneys have been closed up with erupted material, generally agglomerate or tuff, sometimes basalt, and occasionally both kinds of rock together. These filled-up funnels are known as Volcanic Necks.*

A group of vents lies around Burntisland. On the east side a good example of them may be seen by the side of the road to the west of Kingswood Cottage (shown in Fig. 8), where a boss of coarse unstratified agglomerate, about 200 yards in diameter, rises through the sandstones, which may be traced close up against it on the east and west sides. The constituents of this rock are thoroughly volcanic, seeing that they consist almost entirely of detritus of fine green basic pumice and dull earthy basalt. Some of the stones are so vesicular as to be true slags. Blocks 3 feet long may be noticed in the mass. Pieces of limestone and black shale are plentiful in some places, while marcasite has been abundantly deposited in the interstices among the lapilli. Another neck pierces the strata above the limestone at Kilmundy, and is filled partly with agglomerate, in which palagonite is well represented, and partly with basalt. What is doubtless a neck of fine tuff has been pierced in the underground limestone workings at Newbigging, and abundant pieces of the rock have been thrown out with the other rubbish of the mine. But the largest and by far the best exposed and most instructive vent in the district is that of The Binn of Burntisland. This conspicuous hill, rising almost from sea-level to a height of 631 feet, affords a fuller insight into the interior of a volcanic chimney than any other example in the district, or perhaps even in the British Islands. A detailed description of its structure will therefore serve as an explanation of this type of geological structure.

As expressed on the map, the shape of the mass of material forming The Binn is somewhat irregular. It seems to consist of two masses joined together, the smaller of which forms an oval boss,

* In Chapter XV. a general and more systematic account will be given of the Volcanic Necks, Sills, Bosses, and Dykes of the Carboniferous system as a whole, where their connection with any special volcanic period cannot be so satisfactorily determined, as in the case of the Burntisland series described above.

measuring perhaps 1500 feet from west to east, and 700 feet from north to south. The larger boss is more nearly circular in outline, with a diameter of about 1500 feet. Not impossibly each of these eminences may mark a separate orifice, once active during the volcanic period, but the material that fills them has coalesced along their adjacent margins, so as to form now one continuous mass.

It will be observed that each of the bosses rises abruptly through the surrounding strata, which have been so entirely removed that their truncated ends now abut against the walls of the volcanic funnel. On the east side, for example, the limestone, with its overlying shales and oil-shale, has been, as it were, punched out of the earth's crust. On the west side the same effect can be still more clearly seen, where the limestone, with its overlying sandstones and shales, has been in like manner blown away, and where the geologist, tracing the sedimentary rocks up against the tuff, may follow the actual boundary of the vent up the southern slope and round the declivity on the north side of the crest.

The material that fills this important orifice consists of tuff and agglomerate, pierced by a few veins of basalt. It has been laid bare in a range of picturesque precipices, which descend from the summit of the hill into the screes and brushwood that cover their base. A walk along the bottom of these cliffs with occasional ascents into their gullies will reveal to the geologist the internal economy of a volcanic chimney.

The tuff is of the usual dull green colour, and is made up of the detritus of the basalt-lavas, with abundant pumiceous lapilli, such as have already been described. It varies in texture from point to point, some parts being fine compacted volcanic dust or sand, while others are so crowded with blocks as to become coarse agglomerates. The onclosed stones mainly consist of compact dark blue basalt, and of the pale earthy scoriæ and amygdaloids. They vary in size up to blocks a yard in diameter, and are angular, subangular, and rounded in shape. With these stones occur also fragments of the strata through which the vent was drilled. Pieces of limestone and shale are conspicuous, and show no trace of alteration, for they still retain, in perfect preservation, their cyprids and fish-coprolites, the latter still showing enclosed glistening minute fish-scales and bones. A single block of limestone full of cyprids and plants was found to measure some 9 feet long by from 2 to 3 feet broad, and to be planted vertically in the rock so as to project on the face of the cliff.

Much of the coarser parts of the rock is a tumultuous agglomerate, with no perceptible arrangement of its component materials. But even there, occasional more or less distinct traces of bedding can be detected, usually placed at high angles of inclination. Among the finer portions of the tuff, stratification is more distinctly traceable, though it rapidly disappears with increasing coarseness of the material. Strata of alternate finer and coarser

tuff may be seen standing on end with an east and west strike, while further up the cliff they dip towards north-east at 40°, the intermediate and surrounding portions of the mass being destitute of arrangement, but showing their projecting blocks imbedded utterly without order.

This occasional stratification, the strikingly disordered condition of the beds, and their steep angles of inclination are characteristic features of the tuffs and agglomerates that occupy old volcanic vents. The materials ejected from a volcano acquire a more or less distinctly stratified arrangement when they fall on the inner slopes of the crater, and during subsequent explosions and subsidences much dislocation and disturbance of them must take place. As blocks of consolidated tuff drop down into the vent they will generally or often come to rest in vertical or steeply inclined positions, and will be surrounded by more irregular and unassorted material. Such seems to be the explanation of this internal structure of The Binn.

Another characteristic volcanic feature of the precipices of this hill is the manner in which dykes of dark basalt run up their faces. These dykes sometimes die out before reaching the top of the cliff, ramify in the tuff, and project above it as hard outstanding ribs. Some of them are columnar, the columns being arranged horizontally between the two walls, so that when the surrounding tuff has weathered away the side of the dyke presents a wall built up of the close-fitting ends of the columns.

Standing on the brink of one of the deep semicircular chasms, which the rains and frosts of long centuries have sculptured down the front of The Binn, the geologist needs little effort of the imagination to realise what must have been the condition and aspect of the ancient volcano. He can readily fancy that the steep rugged walls around him, studded with their projecting blocks and bombs, furnish a close parallel to what must have been the form of the inside of the crater. The greenish-grey ash-like tuff, resolved by the action of the atmosphere into its original condition, crumbles into loose detritus, and sends its screes of rubbish down the slopes, filling up the rain-channels, till the next storm once more clears them out, and sweeps the ruin of the cliffs down to the plain below.

There appears to be little room to doubt that The Binn of Burntisland marks the position of the chief centre of eruption in the

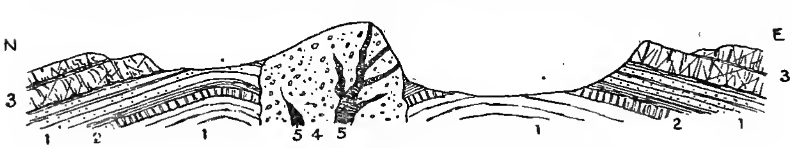


FIG. 14.—Section to show the connection of the Volcanic Vent of the Binn of Burntisland with the surrounding lavas and tuffs.

1. Burdiehouse Limestone group. 2. Burdiehouse Limestone seam. 3. Interstratified lavas and tuffs, with included shales, coals, sandstones, and limestones. 4. Agglomerate and tuff of the vent of the Binn. 5. Basalt veins.

district during the period of the Burdiehouse Limestone group, and that from this centre the lavas and tuffs of the surrounding country were discharged. Reference has already been made to certain indications that the volcanic materials of the coast-section came from some source lying towards the west. A section drawn across the hill in an easterly direction to the lavas of King Alexander's Crag and Kinghorn, and in a northerly direction to those which lie between The Binn and Auchtertool, explains this relation of the vent. (Fig. 14.)

Necks filled with lava-form rocks are hardly to be distinguished from bosses that may never have had any communication with the surface. But in some cases the position of the supposed neck amid tuffs and lavas, and the composition of its infilling material may afford a strong presumption in favour of its volcanic origin. An instance of this somewhat doubtful kind is supplied by Dunearn Hill, a mile and a half to the north-west of Burntisland. Rising to a height of 730 feet, it forms an eliptical eminence that measures about 1500 feet in length from west to east, and 1000 feet in breadth from north to south. It consists of a basic basalt of the limburgite (p. 82) or picrite type and appears in the midst of a wide expanse of volcanic tuff. If the immediately surrounding portions of this tuff could be proved to have the neck-like characters of that of The Binn, there would be no doubt about the origin of Dunearn Hill. The petrographical relations of its basalt link it with the volcanic series and with some of the rocks that occur intrusively in the agglomerates of necks.

(iii.) SILLS, BOSSES, AND DYKES.

The third type of structure in which the igneous rocks associated with the Burdiehouse Limestone group are found is one that has been determined by the manner in which molten material has been injected into the earth's crust. The shape assumed by the material on cooling has in this type depended on the form of the cavity into which it has been propelled. Where the injection has taken place between the planes of stratification, flat tabular masses or sheets of igneous rock, known as *Sills*, have been produced. Where the channel of escape has been an orifice drilled through the earth's crust the resultant shape assumed by the molten rock is an irregular column which terminates at the surface in a variously shaped eminence known as a *Boss*. But many so-called bosses are really more of the nature of sills (or laccolites), from which the original overlying sheet of rock has been removed and which have been carved by denudation into forms entirely different from their first contours.

The Sills and Bosses that traverse the Burdiehouse Limestone group of the Burntisland district may belong to a much later time than the lavas, tuffs, and necks that have been described in the foregoing pages, and might be most logically included with the others to be described in Chapter XV. But, for the sake of com-

pleting the account of this interesting district, an account of them is inserted here. Some of them, indeed, are not improbably underground intrusions from the same great magma which supplied the volcanic eruptions that reached the surface.

The intrusive rocks around Burntisland are all basic, and belong to the family of the dolerites and basalts. They may be arranged in two groups, one of which is free from olivine, while the other contains that mineral. But it is noticeable in this district, as in that upon the south side of the Firth of Forth, that there has sometimes been a segregation of the ferro-magnesian minerals towards distinct parts of the sills, so that one portion of a sheet may be highly basic, becoming even a picrite or limburgite, while in its main mass felspar may predominate to the partial or entire exclusion of olivine.

i. OLIVINE-FREE ROCKS.—These are all dolerites, and may be divided petrographically into the following groups according to the classification of Dr. Hatch and Mr. Watts, already referred to :—

(*a*) *The Ophitic type.*—In this variety there is no ground-mass. The felspar and augite occur in ophitic intergrowth, and there are present also apatite and iron-ores and usually some decomposition products (chlorite, &c.). As an example, the uppermost of the three Burntisland sills may be cited.

(*b*) *The Burntisland type.*—Occasionally some interstitial altered glass remains as a ground-mass, sometimes a little quartz. Granular augite is present, together with a mesh of rather large lath-shaped felspars, which here and there penetrate another unstriated felspar (not orthoclase). The typical examples are the lowest and middle sills on which Burntisland is built; others are to be seen at Colinswell, on the shore a little west of Burntisland, and in one of the sheets exposed upon the shore, on the east side of the cave near the Poorhouse, between Kinghorn and Seafield.

(*c*) *Bowden Hill type.*—In this variety the dolerites unite some of the characters of basalts. While in appearance somewhat coarsely crystalline dolerites, examined microscopically they show a ground-mass which is more plentiful than in the two previous types, and which often occurs in large patches. The felspar and augite are related subophitically when together, but the augite shows crystalline contours where it is in contact with the ground-mass. There are also present some interstitial quartz and unstriated felspar. This type is illustrated by the huge sill which stretches northward from North Queensferry.

ii. OLIVINE-BEARING ROCKS.—Of these, four types in this district may be distinguished by petrographical characters.

(*a*) *The Gallaston type.*—These rocks are olivine-dolerites. They are holo-crystalline, and show a subophitic ground-mass, through which the lath-shaped felspars partly penetrate the augite. The porphyritic mineral is olivine, not felspar. The typical rock of this variety has been quarried at the Gallaston whinstone quarry, Kirkcaldy.

(*b*) *The Dalmeny type*, which has already been described as the prevalent variety among the basalts of the lava-sheets. Some of the basalts which have risen intrusively through the tuffs or agglomerates of necks belong to this type.

(*c*) *The Picrite type*, which has also been above referred in the account of the lavas. The basalt of Dunearn Hill may be cited as an example.

(*d*) *The Limburgite type.*—The rocks included in this subdivision are olivine-basalts, presenting a ground-mass of idiomorphic augite, imbedded in felspathic material which is not present in great quantity. As a porphyritic constituent, olivine is more common than augite. An example of this type is found in the intrusion of basalt which has risen through the neck that forms the Hill of Beath, three miles to the north-east of Dunfermline. But a more interesting instance is to be found in the great dolerite sill which has been injected into the Carboniferous Limestone series to the north of Inverkeithing. Though this sill lies on a higher platform than the igneous rocks with which we are particularly concerned in the present section of this volume, it is noticed here, as it not improbably belongs to the same series as that which runs through the Burdiehouse Limestone group. At Pitadro, near Fordel Castle, the upper part of this sill, assuming a more basic character than the other parts, passes into the Limburgite type.

The Sills and Bosses that traverse the Burdiehouse Limestone group in the Burntisland district lie chiefly in the western or non-volcanic ground, though, as has been stated above, they may prove to be more numerous in the volcanic series to the east than has yet been ascertained. The three sills of Burntisland are excellent examples of this kind of geological structure. Their intrusive nature is well displayed along the upper surface of the middle sill, where the dolerite has invaded and baked the sandstones and shales beneath which it has been injected, as may be seen in the railway cutting and along the upper part of the beach to the west of Seamills. The sill seen in the railway at Colinswell is a dull green decomposing rock, which for two or three inches above its pavement of shale passes into the decayed and altered condition known as "white trap." On a much more extensive scale are the dolerite-sills that rise along the western side of the district. One of these begins near the railway, a mile and a half to the north of St. David's, and extends north-eastwards for some

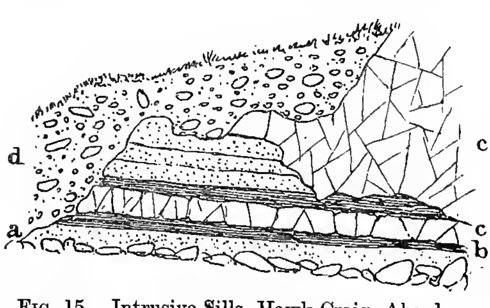


FIG. 15.—Intrusive Sills, Hawk Craig, Aberdour.
a. Sandstone. *b*. Shale. *c*. Dolerite. *d*. Boulder-clay.

six miles, until it is lost among other sills around Auchtertool. It will be seen that this sheet of igneous material, which may be 200 feet thick, though it approximately coincides with the general strike of the strata, as shown by the outcrop of the Hurlet Limestone, does not strictly adhere to one plane. Near Stewart's Arms Inn, while keeping its own dominant trend, it breaks across some 400 or 500 feet of strata, so as actually to reach the Hurlet Limestone.

Perhaps the most instructive examples of sills in the Burntisland district are those laid bare along the shore between Aberdour and Dalgetty Bay. The Hawk Craig at Aberdour (Fig. 15), which reveals both the upper and under surfaces of an intrusive sheet, shows how the molten material has separated into distinct though connected sills and veins, and affords illustrations of the induration produced by the contact of the heated material with the strata. A little further west, three parallel dolerite sills are successively exposed along the shore. The lowest of them has been folded along the line of an anticlinal arch, of which it forms the axis. It is first seen at Port Haven, where the strata dip away from it towards E.S.E. At the Bellhouse Rocks the sandstones are jointed in such a way as to weather into irregular columns—possibly a result of the influence upon them of the underlying dolerite. Immediately to the west of the sill, the sandstones may be seen dipping north of west along the shore of Barnhill Bay. The sill is best exposed at the south end of that inlet, where it forms the headland of Charles Hill. The rock is there seen to be strongly amygdaloidal, its cavities being filled with calcite, quartz, and chalcedony. It often encloses fragments of highly indurated sandstone and shale. It is somewhat decomposed, and weathers into spheroidal blocks. Immediately above it, on its western side, a band of cyprid limestone like those of Burntisland supervenes, and dips westward under a series of sandstones and shales, among which lies the second sill, exposed on the beach at the southern end of Braefoot Bay. A further group of sandstones and black shales lies above this intrusive sheet, and continues the westward dip at an angle of 25°, until it quickly passes under the third and thickest sill of crystalline dolerite, which forms the promontory of Braefoot Point. Thence this sheet of intrusive material stretches inland for upwards of a mile and a half to the village of Aberdour. It has a breadth of outcrop amounting to from 1000 to 1800 feet. At its seaward end it measures 1100 feet across, and if we take its angle of dip to be the same as that of the neighbouring strata, viz., 25°, it must be at least 450 feet thick. Its actual top is concealed by the accumulations of the beach.

Opposite to the sills just described lies the island of Inchcolm, where sandstones, shales, and limestones of the Burdiehouse Limestone group are invaded by other sills consisting in part of a beautiful picrite, which has been several times described and is now well known to petrographers.* The adjacent

* See *Trans. Roy. Soc. Edin.*, vol. xxix (1879), p. 506. Teall's *British Petrography*, p. 94.

islands and those above Queensferry are likewise portions of sills.

The olivine-free dolerite mass of North Queensferry, along its natural escarpments and in numerous artificial excavations made in quarries and railway cuttings, displays a series of instructive sections with regard to the internal structure and variations of a great sill.

To the north and east of Burntisland a number of irregular intrusions have taken place, some of which may be described as Bosses, while others unite certain of the features of sills, bosses, dykes, and veins. As good examples of bosses, reference may be made to Dunearn Hill and the group of eminences which lie to the eastward of it and stretch behind The Binn. Of the more tortuous shapes assumed by the intrusive materials some admirable illustrations may be studied in the Dodhead limestone quarry, in the cliff to the south-west of Dodhead, and in the old limestone quarry of Kilmundy (Figs. 16 and 17).

In the Dodhead quarry the thin sill occurs which has been already referred to as interstratified among the shales, like a thicker band of sediment. Its truly intrusive character, however, is revealed at the end of its course, where the structure is presented

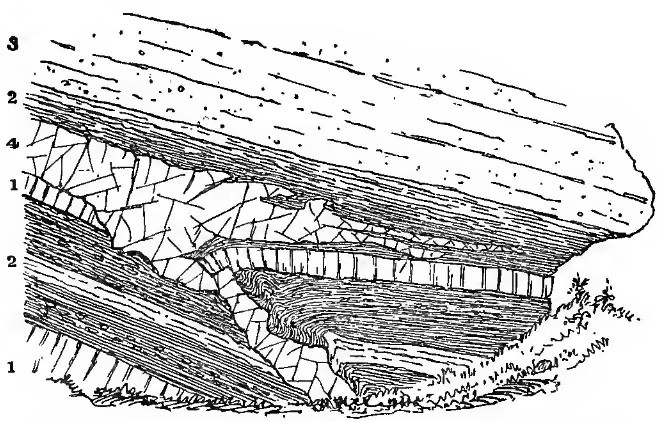


FIG. 16.—Sill among the shales above the Burdiehouse Limestone, Dodhead Quarry, Burntisland.
1. Limestone. 2. Shale. 3. Sandstone. 4. Sill and dyke.

which is shown in Fig. 16. The intrusive rock is a dull yellow, earthy basalt, crowded with small amygdales of calcite. While burrowing its way between the shales it sends tongues into them from its upper surface and splits up horizontally into two sheets, which die out among the shales. Moreover, a portion of its lower surface, probably marking the line of rupture up which the molten material ascended, branches off as a vein or dyke which breaks obliquely across the limestone and shales, crumpling them in its progress. As usual, where one of the basic eruptive rocks comes in

contact with carbonaceous strata, this rock assumes the soft, bleached, earthy condition known as "white trap."

Another instance of irregular injection may be seen on the face of the cliff between Dodhead and the high road half-a-mile east from Burntisland. There the basalt has been thrust among the limestones and shales, partly as a sill which projects an offshoot into them, and partly as a dyke-like mass which ascends vertically through them, sends a tongue into them, and has involved portions of them within its mass (Fig. 17).

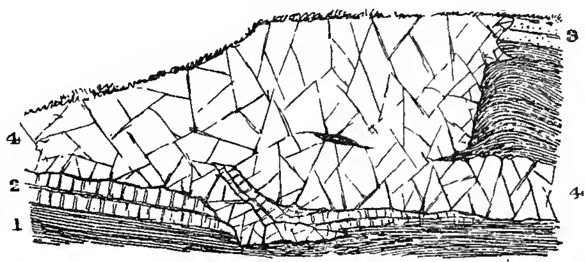


FIG. 17.—Basalt invading strata of the Burdiehouse Limestone group, cliff west from Dodhead Quarry, Burntisland.

1. Shale and limestone-ribs. 2. Limestone and shale. 3. White sandstone. 4. Basalt.

Dykes and Veins are illustrated by some good examples in this district. The largest and most conspicuous dyke is that which extends in an east and west direction for nearly a mile on the coast at St. David's. It has a breadth of about 100 feet, and has risen through sandstones and the sheet of tuff which there overlies them. It projects eastward in the promontory of Downing Point, and the white sandstone on either side of it can there be seen to have been disrupted and indurated. The rock of which it consists belongs to the Bowden Hill type of the olivine-free dolerites. Though its direction might lead to the inference that it may belong to the Tertiary system of dykes, its internal composition and the absence of any other probably Tertiary dyke in its neighbourhood suggests that it may rather be assigned to the much older igneous phenomena of this district.

The dykes and veins of The Binn, which have been already mentioned, may be cited as typical examples of this kind of geological structure. They occur in the neck, which probably marks the position of the chief vent from which the Burntisland volcanic series was ejected. But except in the orifices of discharge, the Carboniferous volcanoes of this district do not seem to have given rise to dykes of normal character. Some of the subterranean extravasations of molten material took the form of irregular tortuous veins, of which a characteristic instance may be seen in an old limestone quarry at Kilmundy, half-a-mile to the north-west of Burntisland (Fig. 18). There a dyke of dull, earthy basalt may be seen to rise up through the limestone, turn along

laterally between the limestone and the overlying black shales, then strike upward for a few inches and apparently end off. That

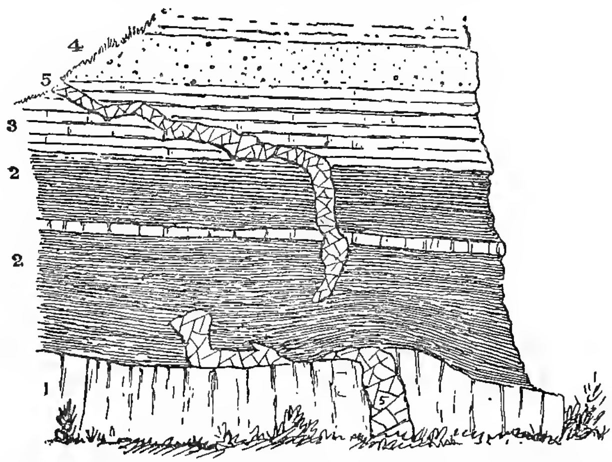


FIG. 18.—Interrupted Basalt-vein cutting strata of the Burdiehouse Limestone group, Kilmundy Quarry, Burntisland.
1. Limestone. 2. Shale and thin limestone bands. 3. Shaly-limestone and shale. 4. Sandstone. 5. Basalt ("white trap").

the molten material, however, continues its ascent probably behind the face of the quarry, is shown by its resumption in the shales a little higher up. It then rises as a somewhat tortuous vein, until is has crossed the rest of the black shales, when it bends at almost a right angle to the left in the overlying grey calcareous shales and winds across these to the top of the section. This rock furnishes a further illustration of the change which basic igneous rocks undergo when they come in contact with carbonaceous materials. It has been changed into "white trap," and now appears as a dull, pale, argillaceous substance, which in a hand-specimen might be taken for a clay rather than an eruptive rock.

CHAPTER VIII.

The Carboniferous Limestone Series.

IN Scotland this important division of the Carboniferous system displays in great perfection the two distinct types of sedimentation already noticed, which may be called the Lagoon or Coal-measure type and the Marine or Limestone type.

In the first of these, the strata are chiefly sandstones and shales, with seams of coal, fireclay, and ironstone. Fossils are abundant, and comprise a considerable variety of terrestrial vegetation, including ferns, calamites, lepidodendroid plants, and some conifers. The animal remains are distinctive. The fishes comprise the Selachian genera *Gyracanthus*, *Tristichius*, and *Ctenoptychius*, and numerous ganoids, among which may be mentioned *Rhizodus Hibberti*, *Megalichthys*, *Rhadinichthys tenuicauda*, several species of *Elonichthys*, *Gonatodus*, *Eurynotus*, and *Nematoptychius Greenockii*. Mollusca are generally absent, but they appear in occasional bands of shale or limestone, and comprise some of the characteristically marine forms of the Carboniferous Limestone. This assemblage of organisms seems to have lived in enclosed basins or lagoons of sea-water, in which the land-plants grew, as mangroves do along tropical shores at the present day, but to which the open sea found occasional access.

In the second type, the strata include bands of limestone, which accumulated in clear sea, since they are entirely built up of corals, crinoids, polyzoa, brachiopods, and other unequivocally marine forms of life. With these limestones are associated calcareous shales, full of the same fossils and marking the influx of muddy sediment from the land. In the following pages many illustrations will occur of the remarkable way in which these two very distinct phases of sedimentation alternated with each other during the deposition of the Carboniferous Limestone series. As a good example of this feature, the following section may be given of the strata that immediately overlie the Main or Hurlet seam of limestone at the Cults Limeworks, above the village of Pitlessie :—

Thick group of dark shales.
COAL, 1 foot to 1 foot 3 inches.
Fireclay, with ironstone balls, 1 foot 6 inches, marking the soil on which the vegetation grew that formed the overlying coal.
LIMESTONE composed of crinoids and numerous other marine organisms, 2 feet 6 inches.
COAL, 10 inches. This seam of compressed land-vegetation is immediately overlain by the limestone.
Fireclay, with rootlets, 2 feet.

Sandstone, with streaks of carbonised plants, 10 inches to 1 foot.
Fireclay, 6 inches.
Blue shales and fireclays, 8–10 feet.
Calcareous shale or shaly limestone, crowded with crinoids, &c., 1 foot 6 inches.
Blue shale, 1 foot 3 inches.
Calcareous shale, richly fossiliferous, 1 foot, passing down into the limestone below.
Thick LIMESTONE, with an abundant series of characteristically marine organisms. This is the Hurlet seam, and a list of its fossils will be found in the Appendix, p. 244.

In this section at least two layers of terrestrial vegetation alternate with limestones formed entirely of organisms that lived in the sea. Each coal-seam has its old soil underneath it, and in the case of the lower seam no layer of other sediment intervenes between the coal and the marine limestone. We may suppose that the whole series of strata was deposited during a time of intermittent subsidence, and that the downward movement between the accumulation of the coal and that of the limestone was comparatively rapid, or at least that it carried the submerged vegetation out of reach of the muddy deposits of the lagoon, so that in clear water the crinoids, corals, polyzoa, and mollusks could begin to live, and to accumulate their remains immediately above the drowned lepidodendra, sigillariæ, and ferns.

Viewed broadly, the Carboniferous Limestone series in Scotland presents us with the records of three distinctly marked periods in the geological evolution of the country. In the first of these, the marine type was prominent, but with alternations of the lagoon type. In the second period, the lagoon type prevails to the almost total exclusion of the other. In the third period, the marine type returned, but on a less extensive scale, and with a much greater development of the lagoon type.

This geographical history is briefly summarised in the threefold stratigraphical arrangement into which the series naturally divides itself, as shown in the table already given on p. 39. We shall consider each of the three groups in consecutive order, beginning with the lowest.

I. THE LOWER LIMESTONES (HURLET AND HOSIES).

Reference has been made in the foregoing pages to the HURLET LIMESTONE as marking the upper limit of the Burdiehouse Limestone group. It is the thickest zone of limestone in the Scottish Carboniferous formations, but varies greatly in development, sometimes diminishing to only 15 feet or less and sometimes swelling out to more than 100 feet. It is a thoroughly marine deposit, which was laid down in a tolerably clear sea, and was built up almost entirely of the remains of marine calcareous organisms. Lists of these fossils from different parts of Fife are given in the Appendix. It may be sufficient to mention here that they include more than a dozen genera of corals (*Lithostrotion*, *Zaphrentis*, *Clisiophyllum*, *Favosites*, *Dibunophyllum*, *Palæacis*, &c.): crinoids of

the genera *Poteriocrinus*, *Platycrinites*; sea-urchins (*Archæocidaris*); holothurians; trilobites (*Griffithides*); polyzoa (*Fenestella*, &c.); numerous brachiopods, especially of the genera *Productus (P. semireticulatus, longispinus, giganteus)*, *Spirifera (S. bisulcata, glabra, trigonalis)*, *Rhynchonella*, *Streptorhynchus*, *Athyris*, *Lingula*, and *Discina*; lamellibranchs (*Aviculopecten*, *Cypricardella*, *Edmondia*, *Nucula*, *Sanguinolites*, *Myacites*); gasteropods (*Bellerophon*, *Macrochilina*, *Loxonema*, *Pleurotomaria*, *Euomphalus*, &c.); pteropods (*Conularia*); cephalopods (*Orthoceras*, several species, *Goniatites*, *Nautilus*); and fishes, chiefly selachian (*Cochliodus*, *Cladodus*, *Pristodus*, *Psammodus*, *Megalichthys*, &c.).

The Hurlet Limestone generally rests on shales among which, throughout Central Scotland, a seam of coal of variable thickness and quality extends, and has in some places been worked. The limestone is overlain with shales which point to the inroad of muddy sediment, by which the life of the organisms and the aggregation of their remains into a tolerably pure calcareous deposit were arrested. That many of the organisms, however, were able for some time to survive this unfavourable change of conditions is shown by their remarkable abundance and perfect preservation in the overlying shales.

We may now follow the outcrop of this seam in its course from the shores of the Firth of Forth at Charlestown eastward through the interior until it bends round again to the coast near Kirkcaldy. The Hurlet Limestone has long been extensively worked and shipped at Charlestown, where fine sections of it have been laid open in the Glen quarries. It is here 40 feet thick and rests on a series of shales (some of which, as at Campsie and elsewhere, are pyritous), with seams of sandstone and some thin coals. It is overlain by other dark shales and sandstones. While the general dip of the seam is towards the north-east, the bedding is a good deal disturbed, being sometimes inclined at angles of more than 60°. The prolongation of the crop eastward has not been traced, owing to absence of exposures, and to the depth of the superficial deposits which here obscure the geology of the ground. The sandstones and shales that lie below the limestone are well displayed along the beach for several miles to the east of Charlestown, but the limestone does not make its appearance there. At Rosyth, indeed, a crinoidal limestone, accompanied with shale, a thin coal and fireclay, may be seen at high-water mark and can be followed for a short distance on the beach. But these strata probably lie in the Calciferous Sandstone series. The black shales a little further west are greatly disturbed and even placed on end. The main crop of the Hurlet seam, if it follows the general trend of the Hosie limestones above, should turn inland towards Dunfermline. Its course, however, is here lost for some miles.

We next meet the undoubted outcrop of this seam at Sunnybank, a mile to the north of Inverkeithing, where, under the drift covering, 8 feet of limestone were quarried, resting upon

18 inches of black shale, below which lay the Hurlet coal 1 foot thick. Further to the east, at Parkend, the seam has been quarried with a westerly dip of 30°. Only its upper portion, with the overlying shales, is now visible. About a mile further north it has been laid open in the Bucklyvie quarry, dipping with an inclination towards W.N.N. at 25°, under fossiliferous calcareous shales. Above the limestone an impure cannel or parrot coal was pierced in a shaft at Easter Bucklyvie mill-dam. In the field immediately to the north, the limestone has been reached in bores at depths of from 15 to 30 fathoms. The outcrop here must bend sharply to the east, for the limestone is next seen close to where the great sill crosses the road, a little to the south-east of Stewart's Arms Inn. Keeping to the outside of the tract of igneous rocks, the seam strikes to the north-east, and has been formerly worked in a succession of quarries as far as Chapel, at the extreme north-east point of its course. The coal below the limestone was cut in the railway half a mile to the south-east of Easter Lochhead. In the large quarries at Chapel and Bogie, the dip of the limestone veers first to the north and then to the east, and the strike consequently swings round at a right angle to its previous course. The Hurlet Limestone must here either split into two bands or a lower seam must come in among the sandstones and igneous rocks below. This lower calcareous horizon may be seen in the form of a sandy, fossiliferous limestone overlying black shale by the side of the road which leads north-west from the farm of Torbain, three-quarters of a mile to the south-west of Chapel. A lower band of limestone, containing *Productus giganteus*, has also been worked at the Foulford Limeworks interposed among the igneous rocks, about a mile south of Chapel.

The intrusive dolerites and basalts of this part of the district have introduced some confusion and disturbance in the strike of the strata. They occur as important sills, which, though on the whole coinciding with the general direction of the bedding of the limestone series, break here and there across it and send tongues into it. Small isolated dykes and veins also occur, like that met with in the Bogie lime-quarry. Moreover, some dislocation of the strike has been effected by faults, of which a large example cuts off the limestone to the south of Bogie, and sweeping seawards shifts the coal-seams and sills at Pathhead. South of this fault, from old pits on the shales overlying the Hurlet Limestone at Potmetal Plantation, near Bogie Mains, a large collection of fossils was obtained by the Geological Survey. (Appendix p. 213.) The intrusive position of the sill in these strata is here well exemplified, the shales being caught between two portions of the eruptive material. The dolerites are thickest in Raith Park and thin away southward, but reach the shore, where they appear on two horizons, of which the lower lies below the Hurlet Limestone, as already alluded to, while the upper is intercalated among the Hosies Limestones. A limestone which overlies the Tiel Burn tuff (*ante*, p. 75) has been extensively worked at Invertiel. Thence

it continues southward. If not the Hurlet seam, it may be the limestone numbered 68 in the detailed section described on p. 74 as visible on the beach near the Kirkcaldy Poorhouse. This seam is undoubtedly, as far as palæontological evidence goes, an integral part of the Carboniferous Limestone series, and ought properly to be included in this place. But as the Hurlet Limestone has been taken as a convenient base for that series, we may regard any lower bands as local forerunners of the more widespread Hurlet seam, and keep them among the strata of the Calciferous Sandstone group.

The Hurlet Limestone, as displayed on the beach immediately to the west of Seafield Tower, is about 50 feet thick, and consists of a number of bands separated by interstratifications of blue shale. At the base, comes a band of grey calcareous shale, 2 or 3 feet thick, with *Spirifer trigonalis* and many other fossils. This band passes down into the black carbonaceous shale already noticed (No. 69, p. 74), and shows how the marine conditions gradually established themselves while the muddy sediment still continued to be deposited. Above it the limestone begins in several bands, altogether about 10 feet thick, containing *Productus giganteus*, and separated by shaly partings. The clear water in which the calcareous organisms abounded and built up the limestone was occasionally invaded by more serious and prolonged inroads of mud, now represented by grey shale or clay. But a large number of the organisms continued to live at the bottom upon which the muddy sediment settled down, for their remains are abundant in the shale. Alternations of limestone and calcareous shale continue until the highest limestone band is reached, which is strongly fossiliferous and about three feet thick. It is surmounted by three or four feet of a shale that passes under the thick mass of pink sandstone on which Seafield Tower stands.

We shall now trace the outcrop of the Hurlet Limestone on the north side of the irregular trough into which the Carboniferous rocks have been thrown. Throughout the western part of the ground, this outcrop is extremely inconstant and irregular, owing to faulting and plication, and partly also to the intrusion of igneous rocks. The furthest appearance of the seam towards the north-west is at Scaurhill, at the western end of the Cleish Hills. It is only seen at the limeworks, and now to but a small extent, as the workings have been long abandoned and are now filled up. It dips in an easterly direction at 10°–15° under about 50 feet of black shales, which are overlain by a dolerite sill. It is cut off to the north by the fault already referred to (p. 41 and Fig. 5), while to the east and south-west its place is at once taken by masses of igneous rock. The relations of this detached outcrop are thus obscured, nor has the seam been detected anywhere among the rock-exposures in the chain of hills lying to the east.

The next outcrops of the limestone are found rising in a singularly disrupted manner on a dome about two miles to the north of Dunfermline. On the north side of the powerful fault which runs westward from Loch Fitty and throws down the Dunfermline

coals, the Hurlet seam has been worked on a great scale at the Lathalmond limeworks, where it dips under its overlying shales and ironstones at 15°, and at the Roscobie limeworks, a little to the north, where the average dip is towards north-east. From the shales above the limestone at these places and at Gask a large series of well-preserved fossils has been collected. (See Appendix.)

The easterly dip brings on higher members of the Carboniferous Limestone series, and the Hurlet seam does not rise to the surface again until it is brought up at the end of the great anticline, and cut through by the fault at Markinch. Underneath that village, a little south of the Parish Church, in excavations for drainage, the limestone was found to be 15 feet thick and to be underlain by shales, including a layer of oil-shale 6 inches thick and a coal-seam of 3 inches. In the present district no further evidence has been found of the position of the limestone beyond this point; the seam, no doubt, folds round the end of the anticline and returns southward against the fault.

The most continuous visible line of outcrop of the Hurlet Limestone is that which circles round the great escarpment of the Lomond Hills for about twelve miles, and runs thence by Freuchie and Cults, until it is cut off by a large mass of intrusive dolerite to the south-west of Cupar. It was formerly much quarried on the Bishop and the two Lomond Hills, and even where no artificial openings have been made, the outcrop of limestone above its platform of black shale, and beneath its cover of shales and white sandstones, can readily be followed. It has been much invaded by the dolerite of the great Lomond sills, and portions of it have been caught up and isolated in the midst of the igneous rock. In one of the largest of these detached areas of limestone, extensive quarries were opened at Clatteringwell, on the Bishop Hill, from which a good collection of fossils was made by the Geological Survey. (See Appendix.) Immediately to the south of these quarries, along the main outcrop of the seam, two beds of limestone may be seen separated by white sandstone. The reader will best be able to understand from the map the effects of the injection of the great dolerite sheets of the Lomonds in disrupting the Hurlet Limestone and isolating it in separate areas far to the south of the northern or main line of outcrop. These detached outliers have once been extensively quarried in three localities—Easter Glasslie, Pitkevy, and Balgeddie. The old workings have partly fallen in, and are now obscured by grassy vegetation. At Glasslie a good face of a strong blue crinoidal limestone in five seams may be seen to a depth of 10 feet 6 inches. A similar limestone of the same thickness, but in three seams, is met with at Newbiggate quarry, close to Balgeddie, where the rock formerly worked open-cast is now mined. It is covered by a thick mass of black shale. The uprise of the Hurlet Limestone in this part of Fife suggests that the Calciferous Sandstones may immediately underlie the dolerite to the west of Leslie.

At the Forthar limeworks, near Freuchie, limestone was quarried on a large scale, but the increasing depth of "cover," as the seams were worked to the dip, combined with the mischief done by a large number of small faults, caused the works to be abandoned more than 25 years ago. The following table will show the alternation of strata at this place above the Hurlet Limestone :—

	Feet.	Inches.
Blue clay or shale (till)	8	
Limestone	4	–
Shale	–	2
Limestone	6	–
Sandstone	–	9
Shale	–	5
Hard sandstone	–	2
Soft do.	1	2
Blue clay or shale (till)	–	4
Sandstone	–	$2\frac{1}{2}$
Coal	–	$\frac{1}{2}$
Red limestone	2	–
Coal	–	$\frac{1}{2}$
Freestone		$5\frac{1}{2}$
Strong clay (till)	–	7
Main limestone (Hurlet)	18	–
Clay or shale (till)	–	3
Coal	–	$\frac{1}{2}$
Freestone	5	

Further east the Hurlet Limestone has long been extensively worked in a line of quarries, stretching for about two miles, and containing the limeworks of Pitlessie and Cults (*ante*, p. 87). Large quantities of burnt lime are sent off from here, chiefly to Dundee and the north-east of Scotland.

Beyond the Cults limeworks, in an easterly direction, the outcrop of the Hurlet Limestone becomes difficult to trace. A limestone was once quarried at Clatto Barns, about a mile south from the Cults limeworks, which may possibly have been this same seam. About three miles further east a number of quarries have been opened in limestone involved among the igneous rocks. One of these lies to the north of Hilltie (Sheet 41). Immediately to the north, a line of old quarries, in what is probably the same seam, may be traced between two sills from Backbraes north-eastward for three-quarters of a mile to Bankhead. This limestone dips gently south-eastward under the great sill of the Garr Hills. Less than a mile further to the north-east, a limestone has been largely quarried near Newbigging of Craighall. It is from 10 to 12 feet thick, dips to the north of east, at 15° to 18°, below black calcareous shales surmounted by white sandstone, and is underlain in the Craighall Burn by black shales and sandstones. There can hardly be any doubt that this is the Hurlet seam. It runs westward by Craighall Castle, plunging under another sill, the edge of which it follows nearly as far as Teassesmill. Further north it must run against a large fault, which, at Ceres, throws down the coal-bearing part of the series against the Calciferous Sandstones.

In Eastern Fife the Hurlet Limestone continues as a persistent seam, notwithstanding the complicated geological structure of that district. Its distribution and development in that part of the country will be described in a subsequent Memoir.

The Hosie Limestones form a group of sometimes as many as five thin limestones, which are separated from the Hurlet seam by a variable thickness of sandstones, shales, and other sediments. This group affords a remarkable example of the alternation of marine and fluviatile or terrestrial conditions. The limestones are made up of crinoids, corals, and other marine organisms; but between them lie sandstones and shales full of land-plants, and even seams of coal, with fireclay-pavements crowded with the rootlets of plants that grew on the spot where their matted remains now lie. These limestones are well seen on the shore north of Seafield, between Kinghorn and Kirkcaldy. Four or five separate seams may there be observed in about 150 feet of sandstones and shales.

It will be remembered that above the Hurlet Limestone at Seafield Tower a thick band of pinkish sandstone supervenes. The usual large development of black shales above the limestone is there absent, or is represented by only some 3 or 4 feet of strata. The sandstone which replaces these argillaceous sediments is succeeded by blue shales, with nodules of cement-stone, and in some places crowded with fossils of marine type, yet including a sandy stratum, full of worm-burrows and remains of terrestrial vegetation. Among the shaly sandstones which succeed these shales, another interesting illustration of the alternation of contrasted sediments presents itself. Above a bed of fireclay full of rootlets lies a thin seam of coal representing the vegetation which grew on that soil and sent its roots downward into it. The coal is one foot thick at the south end of its outcrop on the beach, but thins away northward. It is covered by 2 or 3 inches of dark fireclay, above which lies a prominent bed of hard sandstone, full of vertical worm-burrows. This seam, about 2 feet thick, becomes calcareous in its upper portion, and is there crowded with fragmentary crinoid-stems and covered with well-marked *Cauda-galli* or sea-weed impressions. This calcareous top of the bed contains numerous calcareous concretions, which eventually coalesce and form a thin continuous band of limestone. Numerous corals lie here, evidently in their original positions of growth. In one place may be seen a group of *Lithostrotion irregulare*; in another a large bunch of *L. junceum*. Cup-corals also occur. The transition from the evidence of a surface of terrestrial or at least lagoon vegetation to such a clear sea as allowed crinoids and corals to live is completed within a vertical space of not more than 2 feet.

Above these strata lies the lowest of the Hosie Limestones, which is here between 2 and 3 feet thick. Again we find similar evidence of the rapid alternation of physical conditions, for immediately below the grey fossiliferous shale that underlies

this limestone comes a thin streak of coal, with the usual fireclay-pavement. The limestone has been disrupted by three reversed faults or thrust-planes, which will be described in the account to be given of the dislocations of the region.

The Hosie Limestones have yielded a large number of fossils. But though the species are generally the same as those of the Hurlet Limestone, the individual forms are, as a whole, smaller, as if the organisms had been dwarfed by conditions of life less favourable than those that prevailed when the more massive limestone was laid down. Lists of the fossils of the Hosie Limestones, as developed in different parts of Fife, will be found in the Appendix (p. 246.)

The Hosie Limestones have been worked at various places inland, and may be seen well exposed in some natural sections. One of them has been quarried east and south of Lochgelly and at Parkend. Representatives of the group have been laid open in the streamlets by the side of the Great North Road near Fordel Castle, in the Lyne Burn above Touch Mill, below Touch Bridge, and above Brucefield House. An excellent section of one of the seams may be found in the ravine which winds round the old abbey of Dunfermline. The limestone there exposed is nearly flat, about two feet thick, resting on sandstone and covered with sandy shales. Two seams are well seen in the stream which issues from the peat moss on the east side of Roscobie Moor. They are separated by about 25 feet of sandstone and shale, and the lower seam, 2 or 3 feet thick, lies upon blue shale, with a thin coal. Good sections of one of the seams are to be seen to the west of Roscobie Hill, in the stream at Linn Bridge, and in the line of quarries to the westward.

Some excellent exposures of the Hosie seams may be studied on the shore to the west of the great display of the Hurlet Limestone at Charlestown. The strata that overlie that limestone form low ledges along the beach. First come the black shales, followed by fissile and carbonaceous sandstone, having a general W.N.W. dip at angles of from 5° to 10° for some three hundred yards. The strata then begin to undulate and to dip towards a mass of green tuff which appears near low-water mark. This is not improbably a volcanic neck, but its structure and its relations to the surrounding rocks are much obscured by the accumulation of estuarine mud and gravel on the flat beach. On the west side of the muddy flat of Ironmill Bay two or perhaps three thin limestones represent part of the Hosie group. They are seen at Kinniny Point, where they have been invaded by some basalt protrusions, the shales in contact with which are twisted. From this point the limestones can be followed westwards along the beach for nearly a mile. The subjoined table shows, in descending order, the association of strata at the Chalybeate Spring:—

	Feet.	Inches.
Black shale, with nodules and bands of clay ironstone ...	6	–
LIMESTONE	2	–
Black pyritous shale	1	–
Coal (pyritous)	–	3 to 4

	Feet.	Inches.
Black sandy shale		6
Black pyritous shale, with nodules of clay-ironstone and an eight-inch sandy, ferruginous band, with concretions of ironstone	2	–
Fissile ripple-marked yellow sandstone, with plant-remains	5	–
Black shale		–

The internal structure of this band of limestone is here well displayed, and may be illustrated by the following section, which brings before us the biological conditions in which these calcareous deposits were accumulated :—

	Inches.
Hard black limestone, with *Cauda-galli* on surface, and containing abundant crinoid joints and fragments of shells	9
Band of *Lithostrotion*, the stems mostly prostrate or slightly inclined, with a few *Producti*, &c.	3 to 4
Limestone, made up of fragmentary *Lithostrotion*, *Crinoids*, *Producti*, &c.	2 to 3
Bands of *Lithostrotion*, thickly matted together, the stems inclining upwards	3 to 4
Limestone, full of crinoid joints and fragmentary shells, becoming shaly at the base	4
Shale pavement, including calcareous bands covered with *Cauda-galli*	–

CHAPTER IX.

The Carboniferous Limestone Series—continued.

II. The Lower Coals.

The assemblage of strata now to be described is distinguished by including a number of valuable seams of coal and ironstone. It forms the whole of the coal-fields of Fife to the west of Dysart, and includes the most valuable minerals. It follows conformably on the top of the Hosie Limestones, while its upper limit is fixed by the Index Limestone, which is the lowest of a group of two or three marine limestones that form the uppermost subdivision of the Carboniforous Limestone series. The total thickness of the whole group of coal-bearing strata from the uppermost Hosie Limestone to the Index seam may be set down as about 1000 feet.

It will be seen from the map that the lower coal group (Edge-Coals of Midlothian) extends in a north-easterly direction, between the Burntisland district on the one side and the line of sills which rise above the Old Red Sandstone on the other, but that its distribution has been made singularly complicated by plication and faulting. Beginning on the shore at Kirkcaldy, the series continues comparatively regular with an easterly and north-easterly dip until it bends round into the main syncline at the Clunie Colliery. But thereafter all is apparent disorder. No member of the series can be followed far on any continuous line. The crops are shifted by innumerable dislocations, but, what is more important, the strata have been thrown into many minor basins, so that the outcrops are repeated again and again, not only along the length, but also across the breadth of the main synclinal fold. The district has been so long explored in mining operations that its exceedingly complex structure is now fairly well known, though there are still minor areas respecting which further information is desirable. The most convenient mode of describing the ground will probably be to divide it into a few districts, which may be grouped as follows:—1, the Dunfermline field; 2, the Lassodie and Kelty fields; 3, the Lochgelly field; 4, the Kirkcaldy field; 5, the Markinch and Balbirnie fields; 6, the Rameldry field; 7, the Kilmux field; and 8, the Saline, Oakley, and Torryburn fields, which geologically form part of the Clackmannan Coal-field. It will be understood that in these several districts we are at present only concerned with the coal series between the lower and upper group of limestones. The coals in the latter group will be taken

by themselves in connection with the limestones among which they lie. The fields of coal above the Millstone Grit will come into a still later section of this volume.

i. THE DUNFERMLINE FIELD.

One effect of the plication and faulting above alluded to has been to throw the strata into a number of more or less distinct basins or "coal-fields." The Dunfermline field may be regarded as beginning about Carnock and stretching thence eastwards to Moss Morran, where it merges into the Lochgelly field. Its southern limit is defined by the outcrop of its lowest coal-seam, and its northern margin by a series of powerful faults which throw out the coals in that direction. To the west of this field another basin begins in which the strata dip westward to form the outer margin of the Clackmannan and Stirlingshire Coal-field. The portion of the eastern lip of that basin which comes into Fife will be described at the end of the account of the other Fife fields.

The history of the working of coal around Dunfermline takes us back to the earliest mention of this subject in any Scottish chronicle, though from the language employed in regard to it we may infer that the working of coal was familiar in Scotland long before the end of the 13th century. In the year 1291, William de Oberwill, Laird of Pittencrieff, an estate adjoining the town and abbey of Dunfermline, granted to the abbot and convent of Dunfermline a carbonarium, or coal-work, in his lands of Pittencrieff. The ecclesiastics were to be at liberty to open the carbonarium wherever they pleased, save on arable ground, and when it was exhausted they were to be entitled to open another as often as they judged expedient, it being understood that while they might take what coal was necessary for their own use, they were not to sell it to others. They had likewise authority to quarry stones for their own use on any part of the estate, except on arable ground; and they were to have free use of all the roads and pathways on the estates of Pittencrieff and Gallowridge. The original mode of working coal, as the language of this Charter plainly shows, was to quarry it along the crop and to abandon the excavation when, owing to the increase of water, or otherwise, it became too deep to be further worked. Nor was any other method available before the invention of pumping machinery, and it continued in use until almost our own day. The surface of the ground would thus be pitted over with holes, and as the coal could only be gained when it reached or came near the surface, these old workings would commonly be situated along the banks of a river where the strata might be seen cropping out. The broken form of the ground on some parts of the bank of the South Esk, in Midlothian, and similar traces along the ravine of the Tower Burn and its vicinity at Dunfermline, may indicate some of these most ancient diggings for coal in Scotland.

The succession of strata and the names of the principal seams of

coal are shown in descending order in the accompanying vertical section of the field:—

	Feet.
LOCHGELLY BLACK-BAND IRONSTONE	2
Strata	60
LITTLE SPLINT COAL	4
Strata	18
FOURTEEN-FOOT COAL	6
Strata	35
SIX-FOOT COAL OF TOWNHILL	6
Strata	50
CAIRNCUBBIE (DUDDY DAVY, DEAN) COAL	3
Strata	70
SWALLOWDRUM COAL	7
Strata	100
EIGHT-FOOT COAL	8
Strata	120
FIVE-FOOT COAL	5
Strata	50
TWO-FOOT COAL	2
Strata	15
SPLINT COAL	4
Strata	70
STINK COAL	2
Strata	130 to 200
LIMESTONE (Hosie)	3
Strata	100 to 250
LIMESTONE (Hurlet)	—

SPLINT COAL.—This, which is the lowest workable seam in the Dunfermline coal-field, has long been celebrated as a steam-coal. It has sometimes been known as the Four-feet coal, its thickness varying between three and four feet and sometimes exceeding the latter number. An analysis of it from Lassodie, made by Dr. Percy at the Royal School of Mines, gave the following result:—

Carbon	81·21
Hydrogen	4·40
Oxygen and Nitrogen	12·56
Sulphur	·52
Ash	1·31
	100·00
Coke, per cent.	58·00

Evaporative power calculated from the composition, for 1lb. of coal 13·32lbs. of water.

An analysis of the same coal from the Elgin Colliery, by Dr. Anderson of Glasgow, gave the subjoined result:—

Carbon	81·20
Hydrogen	5·16
Sulphur	0·84
Nitrogen	1·33
Oxygen	10·61
Ash	·86
	100·00

Over a great part of the field the Splint Coal has been worked out. It is the deeper parts, and more particularly the ground to

the north-east, which has been comparatively recently opened up, that yield the present supply.

As the crop of the Splint Coal defines the southern edge of the Dunfermline field, and serves to show, by its frequent dislocation, the general effect of the numerous faults that traverse the basin, it may be usefully traced here from the western to the eastern end of the field. Though, of course, the coal itself has long been exhausted in the southern shallow parts of the basin, which have been longest worked, its outcrop can be occasionally seen, and can generally be satisfactorily made out from the coal-smuts that mark old crop-workings, as well as from bores and pits.

Beginning, then, at the western end, we may note that this coal seam has in recent years been proved to lie in a separate little basin beyond the main field, on the south side of the railway near Carnock, as shown on the map, where also it will be seen that this detached basin, about a mile in diameter, is cut off by a large east and west fault. The seam probably crops out again a little further west, near Pitdinnie. It comes in still further west with a westerly dip, but this extension belongs to the western or Clackmannan basin.

The most westerly outcrop of the Splint Coal in the Dunfermline basin must begin on the south side of the great line of fault which extends westward from Loch Fitty by the reservoirs into the western or Clackmannan basin (Fig. 19). From the workings in the Elgin Colliery the outcrop may be inferred to pass in a southward direction from a point near the Compensation Reservoir, by Bonnyton, to a line of fault, which, like most of the faults in the field, runs in a north-westerly direction. The effect of this fault is to throw down the strata 50 fathoms to the south, so that the outcrop of the Splint Coal is here shifted considerably to the west. The seam must cross the railway not far from Backmuir (where some of the overlying strata with their coals may be seen dipping east at 10°), until it is once more dislocated by the great east and west fault, or "Whitemyre dyke," which has a downthrow of 35 fathoms to the north. Several other smaller faults contribute to break the continuity of the outcrop.

From the southern end of the Dean Plantation, the crop may be followed by means of the traces of old shallow pits in an easterly direction, along the north side of the igneous mass of Knockhouse Hill. It is seen at the surface in the Colton incline. The old pits at the Pittencrieff sandstone quarry show how it comes eastward, that sandstone being the thick "freestone post" lying between the Splint and the Five-feet seams. The crop then turns northward, descending into and crossing the ravine of the Tower Burn, keeping to the east of Beveridge-well, and bending along the foot of the declivity in front of Springbank, until it reaches a fault which has the usual north-westerly trend. The coal is here thrown down 29 fathoms to the south-west. On the other side of the dislocation it is traceable in the same north-easterly direction to the quarry on the east side of Venturefair, where the same thick

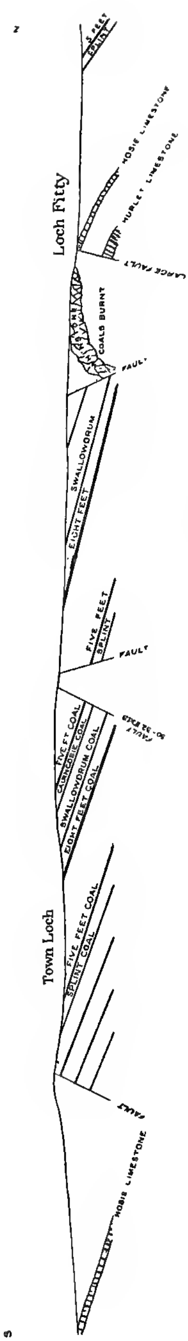


Fig. 19.—Generalised Section across the Dunfermline Coal-field.

sandstone between the Splint and Five-foot seams has been worked. Another fault occurs at this point on the northern side of the quarry throwing the coal down 24 fathoms to the north. Along the hollow, between the Town Loch and Wester Whitefield, traces of old pits probably indicate approximately the crop of the Splint Coal. To the south of the tram-road near Whitefield, and on the west side of the road leading from Whitefield to Touch Bridge, both the Five-foot waste and the Splint seam (probably a pillar) were got in two bores. No record remains of these workings. The coals are here to the south of the proper line of their outcrop. There is therefore either a small outlier detached from the main field, or more probably it is a small area thrown down to the south by a fault. If the fault from Venturefair were prolonged in this direction it would account for this outlying piece of coal.

The further course of the Splint-coal crop eastwards must be nearly coincident with the black patches of coal-dust in the fields where there have been old shallow or crop-workings of coal. From such traces it appears to run by Buckieburn, and thence by Halbeath Station and Morningside, until it comes against a powerful east and west fault, which runs through the Fordel Colliery and has a downthrow to the south of 60 fathoms. Tho crop is thus thrown far to the east. It can be taken up again by the evidence of old crop-workings near Drumcooper, whence, turning more to the south and even to south-by-west, it extends in a singular tongue-like projection into the trough formed by the northward horse-shoe-shaped prolongation of the Inverkeithing doleritic sill. Bending northwards again, the outcrop of the Splint Coal keeps to the east of the Heathermount Plantation, until it again encounters the great east and west fault. Beyond that interruption it was found on the east side of the road at the cottages called Earl's Row. Two faults, one of 20 the other of 10 fathoms, successively throw the coal up to the north at the Cuttlehill Tileworks. The crop then continues in a north-north-east direction into the Donibristle Colliery, passing under

Moss Morran at its southern extremity. There it is interrupted by two powerful faults. The first of these has a downthrow to the south, which at the crop amounts to 20 fathoms, but which increases north-westwards as the workings are pursued under the moss, until it is 40 fathoms. The second dislocation, known as the Moss Morran Dyke, has in the north-western part of its course a downthrow to the south-west usually of about 20 fathoms. The Splint Coal on the further side of these displacements stretches north-eastward into the Lochgelly field.

At the western side of the coal-field in the Wallsend Pit the Splint coal was 3 feet 8 inches thick, and had a pavement of sandstone 10 feet thick and a cover of 6 feet of shale. In the Victoria Pit, which lies 450 yards to the east-south-east of the Wallsend Pit, the coal was found to be 3 feet 10 inches in thickness. In the Wellwood Tom Pit, 330 yards further in the same direction, its thickness is 3 feet 5 inches; while in the Beveridge Pit, a little to the south, it was 4 feet. Further east, at Janefield, near the Town Loch, it was 3 feet 7 inches. Thus, the seam remains tolerably uniform in thickness over a large part of the basin near Dunfermline.

As shown upon the maps, the Fife coal-fields are plentifully interspersed with intrusions of igneous material, but the masses which appear at the surface do not represent by any means all that affect the coal-seams. A number of them do not reach the surface at all, and their existence has only been detected by the alteration which they have superinduced upon the coals near them. As an illustration, which can actually be seen, the accompanying diagram is given. One of the upper coal-seams has been worked along the outcrop where a section has been laid open of a basalt intrusion, part of which overlies and cuts out the coal, while another part has been thrust below the underlying pavement of sandstone. The coal has been much burnt and rendered unworkable. A much larger and not impossibly connected mass of basalt may be seen 500 yards to the east in the Townhill Wood, where it has been quarried. Some parts of the Dunfermline field have suffered considerably from these intrusions of igneous material, as will be immediately pointed out.

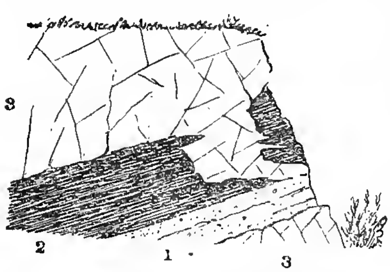


Fig. 20.—Intrusion of Basalt into a Coal-seam, Townhill, Dunfermline.
1. Sandstone. 2. Coal. 3. Intrusive basalt.

Although the injected material has destroyed the coals in close proximity to them, it has not infrequently spread out laterally for a considerable distance without injuring the seams that lie far enough above or below it. It is thus often possible actually to work a coal below one of these intrusive sheets. Around

the actual pipe or dike by which the igneous mass rose, the coal can hardly escape, but where the basalt has been injected between the strata, a coal-seam lying at a sufficient distance below or above it may still be workable. In the instance just cited, at Townhill, a pit was sunk immediately in the basalt, which was passed through and found to be 33 feet thick, while coal-bearing strata were met with underneath it. More rarely the influence of the intrusive rock has actually been beneficial by giving the coal a somewhat anthracitic quality and converting it into a better steam coal. An instance of this kind will be cited in connection with the coal-field to the north of that of Dunfermline.

Even when the igneous rock has not been actually reached in underground workings, its proximity may be indicated by some change undergone by the coal. A striking example of this alteration was encountered in the workings in the northern part of the Wellwood Colliery. The Splint Coal was there found to have been converted into a kind of "blind coal," or coarse anthracite, and to have become useless. It was in the operations from the Leadside Pit, as they were carried north and west, that the change was discovered. "The deterioration commenced always next the roof or at the top of the seam, and increased downwards as the workings advanced, until the whole seam was affected—the coal first losing its brilliancy, and assuming a blueish-black tint, and then accompanied by a very soft and dangerous shale roof, in which the lines of fracture were reversed, gradually losing also the hardness and lamification of Splint Coal, until it passed into an entire cinder. At this stage the working 'faces' were stopped, and a trial-mine, about six feet in width, was driven for several hundred yards to near the north march of Mr. Wellwood's coal-field, where it adjoins Lord Elgin's coal, lying under the lands of Colton, but without coming to anything better—the seam being still at the 'face' of the mine in the state of a soft and comparatively worthless anthracite. The Splint Coal-seam, for nearly the whole of the north part of Leadside farm, is in this state, and also to the west, with the exception of a portion adjoining the Elgin field."* No igneous rock is visible either in the workings or at the surface in any part of the Wellwood Colliery, nor were the seams above the Splint Coal altered. The cause of the deterioration of the coal must have acted from below upward. To the east of Leadside the seam resumed its usual excellent character in the Townhill Colliery.

The Dunfermline basin deepens towards the north-east, where the Splint Coal attains its greatest depth, and is surmounted by the largest number of workable coals. This deepening is not the result merely of the inclination of the strata, but is largely brought about by a series of powerful faults. Some of the more important of these are represented on the map, but they are too numerous to be all shown there. A fault, with a downthrow of 22 fathoms to the north, runs westward from the Halbeath Colliery, and enters

* Chalmers' *Dunfermline*, ii., p. 83.

the Townhill Wood, a little south of the pit above referred to as having been started on the basalt. About 50 yards further north, a parallel fault, also coming out of the Halbeath ground, has a northerly downthrow of 40 fathoms. Hence, in the Muirheath Colliery, only half a mile further north, the Splint Coal has not been reached until a depth of 150 fathoms of strata has been passed through.

The progressive deepening of the field and increase of the distance of the Splint Coal from the surface is abruptly changed by another north-westerly fault, which runs from the Hill of Beath to the upper end of Loch Fitty, where it no doubt abuts against the great dislocation which underlies that sheet of water. The amount of throw of this fault has not been ascertained, but that it must be enormous is shown by the fact that the Splint Coal, which is 150 fathoms deep only 400 yards to the south of the line of fracture, is actually at the surface on the north side, where the fault runs under the alluvium of Loch Fitty.

The great Loch Fitty fault may be taken as a convenient boundary for the Dunfermline field on the north side. The ground beyond it has been carefully explored by boring. As the valuable lower seams of the Dunfermline field began to approach exhaustion, the results of the exploration proved these coals to stretch much further to the north. Though in some places greatly interrupted by faults and intrusions of igneous rock, yet elsewhere the seams were workable, and retained the same good quality for which they had obtained their reputation. This great extension of the coal-field connected the Dunfermline area with that of Kelty. It will be convenient to take the area north of the Loch Fitty fault together with the Kelty ground in the next division of this narrative.

The description which has now been given of the outcrop of the Splint Coal will afford some idea of the general structure of the Dunfermline field, so that a briefer account of the rest of the seams may suffice. In resuming the upward sequence of strata, we next come to the

TWO-FOOT COAL.—Above the Splint Coal, and separated from it by some 10 or 15 feet of black carbonaceous and sandy shales, lies the seam known as the Two-foot coal. In the Victoria Pit this seam consisted of the following divisions:—

	Feet.	Inches.
Shale (roof)	1	1
Coal	1	11½
Fireclay	1	1½
Coal	1	–
"Bands" (pavement)	5	6

In the Wallsend Pit it was only 1 foot 3 inches thick. This seam appears to have been worked to a considerable extent in former times by shallow pits sunk along its outcrop, but it is not now used.

One of the most prominent of the strata between the Splint Coal

and the next seam of importance, known as the Five-foot Coal, is the thick mass of white and yellow sandstone, or "freestone-post," already referred to. It is seen at Pittencrieff Quarry, at Venturefair, and between Whitefield and Halbeath. It occurs in all the pits and bores that have been sunk down to the Splint Coal. In the Victoria Pit it was 45 feet thick in one massive "post," but eastwards it becomes more split up with seams of shale and thin coals. In a bore to the north of the Townhill Loch it was only 14 feet thick, and it becomes still more interleaved with shales and fireclay as it goes eastward.

FIVE-FOOT COAL.—This seam is one of the most valuable in the field. It lies about 10 fathoms above the Splint Coal, and its outcrop follows generally that of the latter seam. In the deep basin at the Elgin Colliery this coal had the following structure:—

	Feet.	Inches.
Shale (roof)	3	5
Coal	2	8
Carbonaceous shale or stone	–	3
Coal	–	10
Shale (pavement)	3	

The seam in this part of the field has all been worked out. In the Victoria Pit it was 4 feet thick, in the Tom Pit (Wellwood) 3 feet 6 inches, with a 3-inch parting of stone. Eastward, on the lands of Jeanfield, it reached a thickness of 4 feet 2 inches, with a 2-inch parting of black shale.

The outcrop of the Five-foot seam, keeping parallel with that of the Splint Coal, can be traced round the basin on the south side. In the Fordel Colliery, where it is 5 feet thick, it has been known as the Coal Thief.

The Five-foot seam of the Elgin Collieries gave the following composition in Dr. Anderson's analysis:—

Carbon	80·93
Hydrogen	5·21
Sulphur	0·63
Nitrogen	1·57
Oxygen	10·91
Ash	·75
	100·00
Proportion of Coke	71·35

The Five-foot seam at Lassodie, according to an analysis by Dr. John Percy, is as follows:—

Carbon	80·99
Hydrogen	5·61
Oxygen and Nitrogen	10·35
Sulphur	·58
Ash	2·47
	100·00
Coke	57·40

Evaporative power calculated from the composition for 1 lb. of coal, 14·63 lbs. of water.

The Five-foot and Splint seams of the Dunfermline Coal-field have long enjoyed a wide reputation as steam-coals, and also for gas-making. They have been extensively used by navigation companies, and were placed on the list of coals used by the Navies of this and other countries. In the "Second Report on the Coals suited to the Steam Navy, 1849," the following results were given from the Wellwood Coal*:—

II.—COMPOSITION OF AVERAGE SAMPLE OF THE COAL.

Sp. Gr. of Coal.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Per centage of Coke left.
1·27	81·36	6·28	1·53	1·57	6·37	2·89	59·15

II.—ECONOMIC VALUE OF THE COAL.

Economic evaporating power, or number of lbs. of water evaporated from 212 by 1 lb. of Coal.	Weight of 1 cubic foot of the Coal as used for fuel.	Result of experiments on cohesive power of the Coal (per centage of large Coals).	Space occupied by One Ton in cubic feet (economic weight).	Pounds of clinker per ton of Coal.
8·24	52·6 lbs.	80·0	42·58	28·5

Subsequently the coal was tried at the Woolwich Dockyard with the subjoined results:—

Pounds of water evaporated to 1 lb. of Coal consumed, calculated from 100° constant temperature of Feed Water.	Cubic feet of Water evaporated per hour, calculated from 100° constant temperature of the Feed Water.	Per centage of Clinker.
7·97	50·25	1·05

EIGHT-FOOT COAL.—This seam, the next of importance above the last-named, is separated from it by about 20 fathoms of various strata, which include some thin coals and clay-ironstones. The Eight-foot seam in the Townhill Colliery consists of the following subdivisions:—

	Feet.	Inches.
Shale and balls of clay-ironstone (roof).		
Coal, soft and foul	2	6
,, clean	1	6
Hard sandstone rib	1	–
Fakes (shaly sandstone)	–	8
Coal, soft and foul	–	10
Coal, splinty	1	6
,, parrot	–	9
,, splinty	1	6½
Hard sandstone (pavement).		

* "Second Report on the Coals suited to the Steam Navy," by Sir Henry De La Beche, C.B., F.R.S., and Dr. Lyon Playfair, F.R.S., presented to both Houses of Parliament by command of Her Majesty, 1849. Appendix, pp. 49, 57.

At Halbeath the seam is split up by a still greater thickness of intercalated strata into two leaves, an upper 3 feet 4 inches thick, separated by from 10 to 18 feet of sedimentary material from a lower, 3 feet 9 inches.

The crop of the Eight-foot seam, on the west side of the Dunfermline field, appears to the west of the Wallsend trough, whence it is probably traceable by some of the numerous old shallow workings visible from fallen-in pits between Rosebank and Drumtuthil. Circling round the deep Wallsend trough, it then bends to the north-east, keeping between the Wellwood Tom Pit and Baldridge Farm, its dip being thus north-westward into the trough, with an angle of inclination of about 20°. Keeping still to the north-east through the Wellwood Colliery, its outcrop was found a little to the north-east of the Waterloo Pit. Thence it runs eastward through the lands of Janefield, the coal having there been worked up to the clay cover. In the Townhill Colliery this seam forms the lowest in a small basin, which is truncated on the north-east side by a strong north-west to south-east fault, having a down-throw of 30 to 32 fathoms to the south-west. The Eight-foot seam crops out a little to the west of the farm of Easter Colton, and circles round by the north-east corner of the Town Loch. It is found a little further east at Halbeath, and again to the south of Crossgates. As the effect especially of two faults with a down-throw to the south, the one of 25 fathoms (passing through Crossgates), the other of 40 fathoms (running through the Cuttle-hill Colliery), the crop of this coal comes once more to the surface some way to the north, and is seen in the railway cutting 300 yards to the south-west of the bridge at Crossgates Station.

While the great value of the Dunfermline Splint Coal has led to its identification in other fields, and to the ready acceptance of its name as that of a coal well known and recognised in the commercial world, there has not been the same reason for adopting the local names of any one field for some of the higher seams, save where the same obvious inducements have come into play. These local names were of course given long ago, before any connection had been established between the different fields, or any attempt had been made to correlate the various seams throughout the whole region. Consequently what may be the same continuous coal may go by a different name in every field. This local terminology has introduced some apparent confusion into the stratigraphical succession in the different parts of the great coal-field. When the nature of the sedimentary strata undergoes considerable modification it is not always easy to be sure of the precise equivalents of any one seam in the different districts. Thus, the Eight-foot coal ceases to bear that name to the east of Halbeath and assumes the name of the Glassee Coal. The Blawlowan coal of Fordel appears to be the same seam.

In following the strata eastward various changes are observable in them, particularly as regards the number, thickness, and quality of the coal-seams which they include. In the Dunfermline field,

as above mentioned, various thin seams of coal are intercalated between the Five-foot seam and the Eight-foot seam. One of these, which is only 15 inches thick, increases towards the east, until, in the Donibristle Colliery, it becomes a workable seam five and a half feet thick, known as the Mynheer. The Eight-foot Coal takes the name of the Glassee in that district, where it consists of two bands, the upper being 5 feet 2 inches thick, the lower 2 feet 4 inches, with a parting between them of fireclay, 1 foot 9 inches.

SWALLOWDRUM COAL.—About 100 feet above the Eight-foot seam, a coal has received the name of the Swallowdrum, from a farm on the Elgin Colliery. In the Townhill Colliery, where it is at present worked, it is 4 feet 2 inches thick, and not always even of fair quality. Traced eastwards it is found to change its character and to become partly a cannel or parrot coal, which is the Parrot seam of Halbeath and the eastern collieries. Lying at Halbeath, about 17 fathoms above the Glassee seam, it is nearly 4 feet thick, consisting of an upper seam of rough coal, 1 foot 2 inches, separated by 9 inches of fireclay from a lower seam of parrot coal, 1 foot 10 inches. In the Donibristle Colliery it attains a considerable development, and begins to include the well-known Lochgelly Splint and Parrot seam. It is there composed of the following subdivisions:—

	Feet.	Inches.
Shale (roof)	–	–
Coal	1	3
Blaes (shale)		6
Coal	–	9
Band	1	–
Coal (Craw)	1	2
Blaes (shale)	–	3
Coal (Lochgelly Splint)	7	3
Blaes and bands	1	
Coal (cherry)	2	–
Dugger	–	3
Coal (parrot)	4	–
Blackband Ironstone	1	
Freestone (pavement)...	21	–

This combined seam crops out about 130 yards to the south-east of the Isabella Pit, in the Donibristle Colliery, whence it ranges north-eastwards under Moss Morran into the Lochgelly field, where it is known as the Lochgelly Splint and Parrot.

CAIRNCUBBIE (DUDDY DAVY, DEAN) COAL.—At Townhill, above the Swallowdrum seam, lies another good coal, 2 feet 8 inches thick, which goes by the names of Cairncubbie, Dainty Davie, or Dean. This seam is also worked further east at Muircockhall Colliery, where it is $3\frac{1}{2}$ feet thick. What appears to be the same seam has been called No. 3 coal in the Cuttlehill Colliery, further to the east, where it is one of the seams which have been exposed to view in the railway cutting to the west of Crossgates Station.

In the Donibristle ground a seam known as the Duddie Davie lies 70 feet above the Splint and Parrot seam. It is 3 feet thick, rests on a pavement of fireclay 8 feet thick, and is overlain with 19 feet of freestone.

SIX-FOOT COAL of Townhill.—This seam, 4 feet thick at Townhill, with another seam known as the Bride Coal (4 feet 3 inches), are the two highest workable coals in the deep, little trough of Townhill. The Six-foot seam is also worked further north at the Muirheath and Muircockhall Collieries, where it is from 3 to 5½ feet thick.

FOURTEEN-FOOT COAL of Cuttlehill, Donibristle, and Lochgelly.—This seam may possibly be the equivalent of the higher coals of Townhill. It crops out in the railway cutting west of Crossgates Station, and again at the Ashley Pit of the Donibristle Colliery. It is thus absent from the southern part of the field, but underlies the centre of Moss Morran, where it is thrown down to the south by two large faults of 30 to 40 fathoms. The outcrop again comes to the surface at the east side of the moss, about 600 yards to the south of Thistleford, whence it ranges north-eastward into the Lochgelly field.

LITTLE SPLINT COAL.—This seam comes in about 18 feet above the Fourteen-foot coal, and, so far as known, is confined to the eastern part of the field. It crops out in the railway cutting west of Crossgates Station, north of which it is thrown out by a fault with a downthrow of 20 fathoms to the south. It appears again beyond Moss Morran and extends into the Lochgelly field. It is about 4 feet thick.

LOCHGELLY BLACKBAND IRONSTONE.—This seam lies about 60 feet above the Little Splint Coal, and has a thickness of 2 feet and upwards. It appears to come only into the extreme east of the Dunfermline field. Its outcrop was cut by the railway immediately to the west of the Bridge at Crossgates Station, beyond which it is thrown out by the large fault just referred to in connection with the Little Splint seam. This ironstone, together with the higher members of the series, will be more particularly referred to in the account of the Lochgelly field, where it has long been worked.

A coal-field which has been worked for so many centuries as that of Dunfermline must necessarily be exhausted over at least those parts of its area where the coals lie nearest the surface. That portion of the ground lying to the north and west of the town is practically worked out. But much energy has been shown in exploring the surrounding districts, so that within the last thirty or forty years new tracts have been discovered and profitably worked. The whole district from the Townhill Colliery north-eastward to Loch Fitty and thence to Blairadam and Kelty has in this way been added to the coal-producing area of the country.

ii. THE LASSODIE AND KELTY FIELDS.

We may now trace the distribution of the coal-seams beyond the limits of the Dunfermline basin as defined on the north by the great Loch Fitty fault. The Splint Coal having been worked under the loch, the position of the fault has been proved in the underground workings. The downthrow of this important dislocation, as has

been stated, is towards the south, but its amount is evidently gradually diminishing eastwards. At Loch Fitty the fault shifts the crop of the Splint coal for a distance of half a mile further east on the north side. This crop must rise to the surface some 500 or 600 yards from the lower end of the lake. It then strikes north-west by Bentymires, whence it bends round in the direction of Braehead, so as to form the lip of another small basin of the Dunfermline coals. The whole district between Loch Fitty, Blairadam, and the Kelty field has been extensively explored by bores as well as by pit-workings during the last thirty or forty years, and a large addition has thereby been made to the area of workable coal in Fife. The ground has been found to be traversed, like the Dunfermline field, by a series of north-westerly faults with a down-throw sometimes to the one side, sometimes to the other, and likewise to be much troubled in some parts by irruptions of igneous material, more especially along a strip between Braehead and Windyedge, where even at the surface abundant outcrops of dolerite may be seen. Nevertheless, some tracts of excellent coal have been found, more particularly the Dunfermline Splint and Five-foot seams. The basin deepens eastwards, until only about a mile from the outcrop of the Splint coal at Bentymires, that seam has gone down to 124 fathoms, a little east of Lassodie Mains. The Lassodie seams have been found to possess qualities similar to those for which the Dunfermline field has been celebrated, as the subjoined analyses by Dr. John Percy will show:—

	Lassodie Splint Coal.	Lassodie 5-Foot Coal.
Carbon,	81·21	80·99
Hydrogen,	4·40	5·61
Oxygen and Nitrogen,	12·56	10·35
Sulphur,	·52	·58
Ash,	1·31	2·47
	100·00	100·00
Coke,	58·00	57·40

Evaporative powers calculated from the composition are, respectively, for 1lb. of Lassodie Splint, 13·32lbs., and Lassodie 5-foot, 14·63lbs. of water.

To the north-west of the Lassodie area, an outlying basin of the lower Dunfermline coals occurs, overlain by the great dolerite sill or "whin-float" of Blairadam. This basin has a breadth of more than a mile on the Blairadam estate. The position of its coals can be satisfactorily fixed, inasmuch as underneath them the Hosie Limestones are found, exactly as at Dunfermline. Two of these limestones crop out in the Lochornie Burn, as shown on the map, and the same seams have been proved in a series of bores as far south as the Blairadam Brick and Tile works. The position of these limestones fixes the southern and south-eastern limits of the

basin. By the help of the sections in the brooks and the evidence of the bores, we can trace approximately the outcrops of some of the coal-seams. That of the Dunfermline Splint Coal has not been detected beyond the mosses that lie to the east of Loch Glow, but from that ground it probably ranges southward across the Lochornie Burn, a little to the east of the limestones. It then circles round the southern end of the great sill, and bending north-eastward, makes for the Glen Burn, south of Blairadam House, where some of the coals have been worked in former times by openings along the outcrop. Traces of such shallow pits may be seen in this glen on both sides of the sill. On the west side, a seam supposed to have been the Eight-foot Coal was mined, where the strata have a dip of 15° to the east. On the east side, the dip is north-westerly under the sill at the Kiery Craigs, and it is there evident that several seams crop out and have once been mined. Two seams in particular have been worked rather extensively to the north-east of Blairadam House. The lower of these is 4 feet thick and the upper 10 feet. They dip towards the north-west, and the workings were in that direction. In the stream that flows close to the north side of the high road, a little south from Kinnaird, one or two bands of volcanic tuff occur, containing calcareous layers which may represent the position of the Index Limestone.

That there is a basin of coal under the Blairadam doleritic sill admits of no doubt. How far the coal has escaped damage by the igneous material can only be ascertained by means of trial bores.

Immediate to the east of this basin the coal seams are folded over an anticlinal arch, and then dip towards the east to form the Kelty Coal-field. This arch is not improbably broken by one or more faults. In a boring put down a little more than 500 yards north-east from Blairenbathie, the strata were found to be on edge. One side of the fold can be easily made out in the Glen Burn. Only 600 yards to the east of the old coal-workings just referred to as visible on the eastern side of the sill, a seam of limestone 4 feet thick may be seen dipping to the south-east at 26°. The return north-westerly dip of this seam further up the glen is not visible; possibly it may be cut out by a fault. But the general structure of the ground can be understood. There can be little doubt that this limestone is one of the uppermost Hosie bands and that the strata which overlie it correspond to the lower part of the coal-bearing series of Dunfermline. This is a point of considerable interest and importance, for a reason which will now be stated.

The coal-seams in the Kelty coal-field, laid open at the crop by the Kelty Burn and the Drumnagoil Burn, which flow in an easterly direction across the field, must early have attracted notice, and were no doubt dug out in surface-openings at a remote date. When pumping machinery came into use, and more extensive mining operations became practicable, these seams were penetrated to greater depths, and gradually the whole series of coals in this detached locality was ascertained. Local names were given to these

seams, and as the field lay at some distance from any other the idea of comparing and identifying the coals with those of other places was not at first likely to occur to the coal-owners. It is not many years since the Kelty coal-field still retained this isolation, and seemed to find no definite place among the coal-fields of Fife. No one ventured to correlate its seams with those even of the neighbouring districts. At last, as the mining of the Lochgelly Ironstone continued to be prosecuted vigorously towards the north, that seam was found on the east side of the Kelty field, and obviously overlay the coals of that part of the district. It was thus clear that the Kelty coals must represent those of Dunfermline and Donibristle. On the other hand, the observation of the Hosie Limestone in the Blairadam Glen proved the Keltie coals to lie immediately above that seam. Their general identity with those of the fields to the south was thus demonstrated.

Yet, when we come to compare the Kelty coals with those of the Dunfermline field, we cannot but be struck with certain notable variations. Of course the local names are entirely different, but the seams themselves and the strata between them have undergone a good deal of change in the intervening two or three miles. The following generalised table gives the names and thicknesses of the seams and their associated strata:—

Table of the Kelty Coals.

	Feet.	Inches.
Freestone	87	–
Shales	12	
ROUGH COAL with a parting of 12 inches	6	–
Sandstones with some bands of shale	100	–
BLACK-BAND IRONSTONE (Lochgelly Ironstone) ...	1	–
Shales and thin coals	25	–
MAIN Coal	4	3
Sandstone and shale	14	–
JERSEY COAL in two leaves separated by a 10-inch stone parting	6	–
Shales and sandstones	65	–
SPLINT COAL (=Kinglassie Splint)	3	–
Dark freestone and shales	86	–
BANK COAL (=Lochgelly Splint)	3	9
Strata, chiefly shales, with a thin clay-ironstone (4 inches), and 12-inch coal below it ...	100	–
LOCHY COAL (? Eight-foot of Dunfermline)	5	
Strata, chiefly shaly sandstones, with some shales	55	–
COAL (Two-foot)	2	11
Strata (chiefly sandstones, generally shaly, with black shales and ironstones)	70	–
GIN COAL (?=Five-foot of Dunfermline)	4	3
Strata (chiefly white freestone, with two coal-seams of 1 foot 4 inches and 1 foot 7 inches)	45	
COAL (?=Two-foot of Dunfermline)	2	
Strata (freestone and shales with a thin, inconstant parrot-coal and ironstone of poor quality)	45	
COAL, Splint (Dunfermline Splint)	4	
White fireclay	2	

The western part of the Kelty field, which, being nearest to the outcrop, was the first to be worked, differs in one important respect

from the Dunfermline field. The largest fault met with in it had a throw of only 8 feet. As the explorations have proceeded eastwards and southwards, however, much more powerful dislocations have been encountered. One of these, running in a north-westerly direction between Hilton and Shiells, has a downthrow of 16 fathoms to the south-west. Another having a similar trend increases greatly in its amount of displacement as it goes south-eastwards, till it has a throw of 40 fathoms to the south-west. Another important fault runs in a nearly east and west direction from Netherton to Cocklaw, and throws down the strata 25 fathoms to the south, thereby bringing the crops of the coals back again further west.

In the southern part of the field at the Lassodie Mill Colliery no fewer than seven of the seams are profitably worked. Of these the lowest or Dunfermline Splint (4 feet 3 inches) affords an excellent household coal. The Five-foot seam of Dunfermline is here $5\frac{1}{2}$ feet thick. Next above comes the Mynheer (3 feet), followed in succession by the Glassee (5 feet), Bank Coal or Lochgelly Splint (5 feet), Cairncubbie (3 feet 3 inches), and Main Coal (4 feet).

Besides dislocations, the Kelty field is not wholly free from intrusions of igneous rock. A thin but persistent sill extends for more than a mile, a little to the east of the crop of the Rough Coal, and dips eastward, like the strata among which it lies. It crops out to the surface in the quarries to the west and north-west of Shiells, and it appears to be brought up again by the effect of a fault at Shiells Farm. It has been met with in several bores in the neighbourhood.

The effect of these intrusions of igneous material upon the coal seams, though sometimes disastrous, is occasionally serviceable, from an economic point of view, as has been found in the Kelty Coal-field. At the Aitken Pit the Splint Coal and the Gin seam, or Dunfermline Five-foot Coal, have been converted into a kind of anthracite, and have thus become, for steam purposes, almost equal to Welsh coal. The Splint Coal, or "Aitken Wallsend House Coal," as it is termed for sale purposes, has been examined by Mr. G. R. Hislop, F.C.S., at the Paisley Gas Works, and he has made the following Report regarding it to the Fife Coal Company, by whom it is worked:—

"The coal is black and possesses high lustre; fracture irregular and partly defined by thin deposits of charcoal; cross fracture angular and highly crystalline to semi-resinoid and of very uniform composition and density; mean specific gravity being 1247 (water 1000); weight of one cubic foot, 77·93 pounds. The coal is moderately cohesive, but very compact and without a trace of lime or pyritic impurities. Its composition is as follows:—

Volatile Matters...	24·27	per cent.
Fixed Carbon	73·56	,,
Ash	1·42	,,
Sulphur	·27	,,
Water at 112° Fahr.	·48	,,
	100·00	

Heating power of the coal as determined by Thomson's calorimeter, 1 lb. of the coal by perfect combustion evolves heat sufficient to convert 14·98 lbs. of water from 212° Fahr. into steam."

The Five-foot seam has also been analysed for the Fife Coal Company by Messrs. Tatlock, Readman, & Thomson, city analysts, Glasgow, with the following results:—

Volatile Matter	Gas, Tar, &c. ...	31·36	33·30
	Sulphur ...	·24	
	Water ...	1·70	
Coke ...	Fixed Carbon ...	63·61	66·70
	Sulphur ...	·47	
	Ash ...	2·62	
			100·

Specific Gravity ...	1·24
Weight of 1 cubic foot in lbs. ...	77·5
Heating power—practical—(lbs. of water evaporated by 1 lb. coal)	9·24

The coal from the two seams, mixed in equal proportions of each, is sold as "Aitken Navigation Coal."

South of the Netherton-Cocklaw fault, which forms the southern boundary of the Kelty field, a fresh field has been opened up by the Rosewell Gas Company on the ground near Lassodie Mill. The Rough and Jersey Coals of the Kelty field are here worked. The Jersey seam is 6 feet 6 inches thick, and a good household

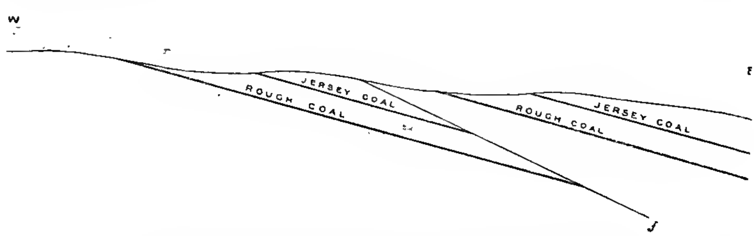


FIG. 21.—Reversed Fault in the Kelty Coal-field.

f. Line of reversed fault. It will be seen that in such dislocations a vertical shaft may pass twice through the same seam, and that the workings in the seam on one side of the fault may actually overlie those on the other side.

coal, though somewhat soft. A remarkable north and south fault, diverging from the boundary fault of the Kelty field, runs through the Lassodie Mill field. It has a low grade with a down throw to the west. It is what is known as a "reversed fault," consequently the two coals are worked on both sides of it, those on the upthrow side actually overlying those on the downthrow side.

CHAPTER X.

The Lower Coals—continued.

iii. THE LOCHGELLY FIELD.

THIS district of the Fife Coal-field extends from Moss Morran northwards to the valley of the River Ore at Colquhally and eastwards to Cardenden beyond Lochgelly. The portion of the coal-bearing series which it contains includes all the seams from those that come immediately above the Lochgelly Black-band Ironstone down to the very base of the series. The following table shows the succession and thicknesses of the several seams, and of their intermediate strata, at the deepest part of the field:—

	Feet.	Inches.
Various strata	30	–
COAL	5	6
Strata	24	–
COAL	3	–
Strata	40	–
COAL (WILLOW BUSH)	4	–
Strata	20	–
COAL (ROUGH OR SPLINT)	3	6
Strata	42	–
LOCHGELLY BLACK-BAND IRONSTONE	2	3
Strata	3	–
COAL, 3 inches to 3 feet	3	–
Strata	60	–
COAL (LITTLE SPLINT)	3 to 4	
Strata	18	
COAL (FOURTEEN-FOOT), varying from 10 to 15 feet, divided by thin ribs of stone in the north part of the field, but southward these ribs increase in thickness so as to divide the coal into five workable seams in 60 feet of the section	15	
Strata	110	–
SPLINT COAL (LOCHGELLY SPLINT)	5 to 7	6
Shales from 6 inches to 6 feet in thickness, with an irregular seam of ironstone, which is sometimes 15 inches thick	6	–
COAL (LOCHGELLY PARROT), the parrot ranges from 6 inches to 3½ feet in thichness	3	6
Strata	130	
COAL (GLASSEE)	3 to 5	
Strata	50	
COAL (MYNHEER of Fordel)	3 ft. 3 in. to 4	
Strata	60	–
COAL (UPPER FIVE-FOOT)	3	10
Strata	54	–
COAL (LOWER FIVE-FOOT)	4	6
Strata	65	–
COAL (MAIN SPLINT, DUNFERMLINE SPLINT)	4	–
Strata	25	–
COAL (SMITHY, partly blind and mixed with blaes)	3	6

In several respects the Lochgelly field presents a geological arrangement of the strata, which marks it off on the whole from the other fields in Fife. Even more than elsewhere, the strata have here been thrown into a succession of troughs and arches, so that the levels in the coals, instead of following straight lines, deflected only by faults, curve round into ellipses. Hence, apart from the influence of dislocations, the seams lie at remarkably variable depths according to the position and magnitude of the plication. The same seam which may in one place crop out at the surface round the summit of an arch or dome will be found at a distance of only a few hundred yards 60 fathoms deep or more.

The unequalities of position are still further increased by a number of faults, some of considerable size, by which the field is traversed in a west-north-west direction. A description of the outcrop of one particular seam will best illustrate this structure. For this purpose the combined seams of the Lochgelly Splint and Parrot and the Black-band Ironstone may be selected.

Taking the outcrop of these seams where it comes from the north-eastern margin of the Donibristle Colliery, we find it to run in a tolerably straight north-easterly course, until it abuts against a powerful fault, which towards the west is said to have a downthrow of 100 fathoms. This fault passes with an easterly course by the Cowdenbeath Station, on the old Edinburgh, Perth, and Dundee Railway, and appears to diminish rapidly in its effects as it goes eastward. The outcrop of the Splint and Parrot seams is probably not much shifted by it, but continues in the same general direction to Loch Gelly, on the northern shore of which it appears, and whence it runs onward against a large fault close to the farm of Muirhead. Its further progress is continuous into the Cardenden and Kirkcaldy field, to be afterwards described. So far the structure is quite regular. The seams dip towards the north-west, are not seriously displaced from their course by faults, and show no tendency to go into troughs or arches.

But only a short distance towards the west, this regularity is exchanged for a much more complex structure. The Splint and Parrot seams are brought up to the surface, and over part of the ground have been entirely removed from it by denudation. To the north of the Cowdenbeath Station fault, above alluded to, a section on the railway, two-thirds of a mile north-east from Thistleford, shows the crop of the Fourteen-foot Coal and the overlying strata, which dip towards N.N.W. at 8° to 10°. Immediately to the west, the rocks have been thrown into a trough, so that the Splint and Parrot, instead of continuing to sink further, are brought up to within 14 fathoms from the surface at the east side of Cowdenbeath Bog. But the trough soon dies out, and the strata resume their north-westerly dip. In the village of Cowdenbeath they are already 55 fathoms deep, while only 400 yards further west they have sunk to 90 fathoms, with a dip of about 10°. The position

of these seams must lie far below the great dolerite sill of the Beath Hills. How large a portion of the coal-bearing series has been preserved under this sill has been experimentally proved by a deep shaft sunk close to the edge of the sill at Dalbeath to a depth of more than 1000 feet. It passed through about 70 fathoms of strata, including a few thin coals, above the position of the Lochgelly Black-band Ironstone, and then through the seams of the Lochgelly, Halbeath, and Dunfermline fields down to the Dunfermline Splint Coal, which was found to be 4 feet 3 inches thick.

To the north of Cowdenbeath another great fault, said to have a downthrow of 50 to 100 fathoms to the northward, strikes in an E.S.E. direction from the sill in the direction of Easter Lochhead. Beyond this dislocation the folding of the strata begins rapidly to increase. The Splint and Parrot seams do not here reach the surface, but the map shows, by the crop of the Ironstone, how the plication advances. The latter seam follows the normal north-westerly dip on the north side of the fault, and crops out along the east side of Blackdean Hill, while the Splint and Parrot are there 70 fathoms below ground. The Ironstone, however, rolls over to the east and is caught in a little basin at Newton, of which the northern lip is cut off by a fault that brings up lower strata again on the north side. The outcrop of the seam is thus shifted to the west upwards of 400 yards.

An attentive examination of the map will show that from this part of the field northwards to its furthest limits, the strata have been upraised into a broad dome or arch, which becomes narrower and more defined towards the north. The shape of this fold and the manner in which it has been affected by faults are admirably illustrated by the outcrop of the Ironstone, and are further explained in Fig. 22. We may follow that outcrop and trace it

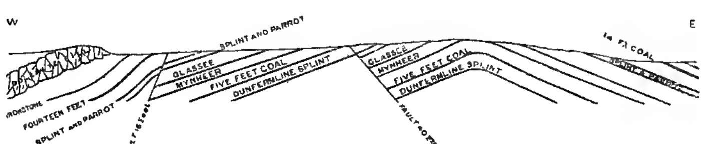


FIG. 22.—Section across the Lochgelly Coal-field from South Lumphinnans on the west to near Lochgelly House on the east.

from the fault last mentioned northwards by Viewfield House to another west-north-west dislocation (shown in Fig. 22), which passes to the south of South Lumphinnans and throws down the rocks 40 fathoms to the south. The outcrop is consequently shifted a little to the west. The angle of inclination of the strata here rises to 35° or more, and the outcrops of the several seams are thus brought closer together. A minor curve on the flanks of the main arch throws the outcrop of the Ironstone round for a short distance to the east, until it is abruptly cut off by a powerful fault, which, running in a north-westerly direction from the village of Lochgelly towards Easter Cartmore, effectually ruptures the arch

on its western side. The effect of this fault is to bring up lower parts of the coal series on the north side, and to throw the outcrop of the Ironstone a long way to the north-west. We catch the fault again near Easter Cartmore, striking north-eastward by Grainger's Square to Wester Colquhally, where it is once more shifted, this time for a distance of about 900 yards to the west. As the angle of inclination has here lessened to only 10°, the faults produce a great horizontal effect on the outcrops. We have now reached the northern end of the dome, where the dip becomes northerly, then north-easterly and easterly, the successive seams folding round and taking their places along the east side. This arrangement is well exemplified by the outcrop of the Ironstone. From the River Ore below Clochrat Bridge, this seam strikes eastward and then south-eastward to near Easter Colquhally, where it bends to the south, until at the Lochgelly Brick Works it is slightly ridged up along the side of the dome, so that the crop makes a bulge towards the east. A large fault then shifts it to the west, but thereafter it continues in the southerly direction, until, as the arch flattens down, it bends sharply to the east and runs parallel with the outcrop of the Splint and Parrot already noticed as striking eastward from Lochgelly.

But a little further study of the map will show that the dome or arch which we have been tracing is not a mere simple fold of the strata, but becomes complicated into a series of folds as it gradually dies out towards the south. We have seen this structure to be well illustrated by the Ironstone near Blackdean Hill. It is even better displayed by the behaviour of the Splint and Parrot. At the south end of the village of Lochgelly, a larger fold in the series of plications has upraised the strata into an elliptical dome about half a mile long, with its longer axis ranging nearly north and south. On the crest of this arch (Fig. 22) the outcrop of the Mynheer Coal comes out to the surface and forms an oval ring, followed by the larger ellipse of the outcrop of the Glassee Coal, which lies about 50 feet higher in the series. The Splint and Parrot outcrop then makes its appearance, forming a yet wider and more irregular oval, which, however, does not quite close at the northern end, on account of the 40-fathom fault coming from South Lumphinnans. Not only is the dome there broken through, but the strata are so upraised on the north side that the coals below the Mynheer seam are brought up to the surface, and the outcrop of the Splint and Parrot is shifted westward for about 700 yards.

Beyond the powerful dislocation above noticed as coming from the direction of Easter Cartmore, the outcrop of the Splint and Parrot has been traced round the northern end or nose of the main anticline, and down the eastern side until it runs into the ellipse south of Lochgelly village. This eastern outcrop is much less affected by faults than the western. But it has been singularly disturbed by the effects of folding. The strata have undergone a

series of minor plications or puckerings, of which the longer axes trend towards N.E. along the eastern slope of the main arch. Consequently the strike is made to undulate and the outcrop makes a series of waves or wriggles to the north of Lochgelly.

iv. THE KIRKCALDY FIELD.

This portion of the district includes all the collieries which lie beyond Lochgelly and south of the River Ore as far east as Clunie, and thence to the sea at Kirkcaldy. The same series of coals and intervening strata is here presented as in the fields further west, but with some local variations. The general succession of measures in the western part of the field is shown in the subjoined table of the strata passed through in the Panny Pit of the Dunnikier Colliery:—

	Feet.	Inches.
Various strata	180	–
UPPER SMITHY COAL	2	9
Strata	150	
COAL (rough and parrot) and Shale (= position of Lochgelly Black-band Ironstone) ...	3	9
Strata	50	–
COAL	2	2
Strata	38	–
COAL (coarse)	3	–
Whinstone	18	
Freestone	24	–
COAL	–	10
Strata	9	10
COAL	1	4
Strata	17	8
BLACK COAL ... ... (Lochgelly Splint and Parrot)	4	-
Strata ... (Lochgelly Splint and Parrot) ...	2	4
PARROT COAL ... ... (Lochgelly Splint and Parrot)	2	6
Strata (including some thin coals and 40 feet of whinstone)	200	–
CARDENDEN COAL (? Glassee Coal of western fields)	4	–
Strata	21	
GIBBS HALL COAL (Mynheer)	2	1
Strata	25	–

The various seams of the Lochgelly field stretch north-eastward, having a gentle northerly dip of only 8° or 10°. In their extension in that direction, they are much less folded and faulted, though here and there they include intrusive sills of igneous rock. A good section of the series of strata from the uppermost Hosie Limestone to the Lochgelly Black-band Ironstone has been cut by the stream that has excavated the Carden Den between Shaws Mill and Cardenden Station. The thin Hosie Limestone crops out at Bairns Bridge. Above it, on the main stream, about 100 yards below Shaws Mill Bridge, the Dunfermline Splint and Five-foot seams cross the bank on the left side of the stream. The seam known in this district as the "Gibbs Hall Coal," probably the same as the Mynheer seam further west, makes its appearance under the ruins of Carden Tower, and the Carden Coal, which may be a

continuation of the Glassee seam, appears 100 yards lower down the ravine. The Lochgelly Splint and Parrot seams crop out at an old sandstone quarry a few yards further on upon the right side of the stream, and, owing to their low angle of inclination, wind along the Den for 300 yards of its course. The outcrop of the representative of the Lochgelly Black-band Ironstone comes in opposite Hyndloup, and the so-called Smithy Coal of the Kirkcaldy field crops out on the left bank at Cardenbank. Beyond that point we reach ground obscured by the alluvium of the Ore valley. But in the course of a streamlet, half a mile to the west, overlying coarse sandstones, with bands of black shale and ironstone, may be seen, still dipping at only 8° to N.W.

Several of the large faults from the Lochgelly field extend eastwards and enter the Dundonald Colliery. One of these passes a little north of Muirhead and south of Shaws Mill. To the south of it another dislocation occurs, and between the two no coals have been met with. Another east and west fault, with a downthrow of 8 fathoms to the north, runs by the north end of the Muir plantation.

The outcrops of the lower Dunfermline seams of coal have not been traced through the Kirkcaldy field. The lowest seams that have been followed are the Gibbs Hall and Carden seams, which, as they approach Kirkcaldy, are known as the Lower and Upper Smithy seams. The Black Coal and Parrot (or Lochgelly Splint and Parrot) crop out at the edge of the Sunnyside sill, which they underlie. These seams were formerly worked in shallow pits sunk through the basalt, while the Carden seam was also similarly worked to the east of Clunie Square, at depths of not more than 16 to 19 fathoms. The Black Coal and Parrot continue in a south-easterly course beyond the end of the basalt-sheet at Mutton Hall, and crop out in the dell of the Chapel Burn a little below Smeaton Row, in the old Dunnikier Colliery. The strata are traversed immediately to the south of that section by a powerful fault which, throwing them down to the south, strikes from the middle of the Pathhead Sands north-westwards to beyond Bogie Parks. The effect of this dislocation is to shift the outcrops 600 yards to the west. Another intercalated basalt, which now begins to make its appearance on the same platform as the Sunnyside sheet, south of Clunie, increases in thickness, and has been exposed in the railway cutting north of Kirkcaldy Station with the outcrops of the two coal seams coming out from under it. Though owing to the depth of superficial deposits no further exposures of the strata are to be seen between the railway and the sea, it is not improbable that the igneous rock just referred is prolonged to the south and forms the long narrow tidal reef known as the Long Craig, lying to the east of Invertiel.

The Splint and Rough coal-seam of the Dundonald and Cardenden Collieries is known as the Clunie Coal, when it comes east into the Clunie Colliery. From Hyndloup, where it appears in the ravine, its outcrop runs eastward by Clunie Square, Coalden,

and Begg, till it begins to bend with the other coals south-eastwards to the sea. The combined seam can be mapped as two separate beds in the latter part of its course. The two seams have their outcrop in the ravine of the Dunnikier Colliery, a little further down than those of the Black Coal and Parrot.

The Smithy Coal of Dundonald and Cardenden, from its outcrop at the foot of the Carden Den, strikes eastward into the Clunie Colliery and is exposed for 350 yards along the sides of the Clunie Den. Throughout all this part of the field the strata dip at low angles towards the north, and are not seriously dislocated by faults. So gentle is their inclination that 800 yards north from its outcrop the Clunie Coal is only 19 fathoms below the surface. Unless there is much disturbance and invasion by igneous rocks, of which there are no superficial indications, the Kirkcaldy and Dunfermline coals, or at least seams representing them, ought to be found over the ground to the north of the River Ore.

The pit-workings north of Pathhead show the strata to be remarkably regular and undisturbed. The working level runs in the Black Coal and Parrot for a mile to the north-west of the Panny Pit, and shows only one serious displacement caused by a fault with a downthrow of 6 fathoms to the north. This pit, the section of which has already been given, lies immediately to the north of Pathhead. It struck the Rough and Splint seams at 57 fathoms and the Parrot at 90 fathoms. The levels in the pits further to the north-west show the same undisturbed course. In the St. Clair Pit, to the west of Dunnikier House, the Parrot seam was reached at 66 fathoms, and in the Lina Pit, 350 yards to the north-west, at 74 fathoms. In the latter shaft some igneous rock was met with at a distance of 5 fathoms above the coal. It should be added that all the shallower part of the Kirkcaldy field has long been worked out.

It is a curious fact that, notwithstanding the comparative regularity of the strata in this field, and the small number of serious dislocations, a number of sills have been injected into the coal-bearing measures on several horizons. Two of these are shown in the sections of the Panny Pit (Figs. 24, 25). It will be recollected that two thin sills occur on the beach below the Hurlet Limestone, near Seafield Tower, and swell out to a considerable breadth as they run inland. Above these, two other sheets of dolerite have been intruded above the Hosie Limestones at Tyrie Bleach Works. On the coast they are mere thin seams, but they swell out as they advance into the interior towards Raith Lake. What appears to be the same sheet of eruptive material, shifted by the great Kirkcaldy fault, extends northwards to Bogie. The intrusive nature of this sheet can be demonstrated at many parts of its course. Thus, immediately to the east of Tyrie, in the cutting of the old disused tramway line, the top of the dolerite may be seen thrusting itself under a mass of black shale. The rock assumes the usual close texture and passes into the bleached condition so generally observable where one of these basic rocks has come in

contact with carbonaceous materials. It is finely amygdaloidal, the kernels consisting of calcite encased in a coating of marcasite. It can be observed not to keep the same level, but to break across the shales, sometimes in an upward, sometimes in a downward, direction.

Still more instructive is the section of the same intrusive mass laid open a little further inland in the cutting of the North British Railway. The dolerite has not only been injected between the shales and sandstones, but has broken through them, sent tongues

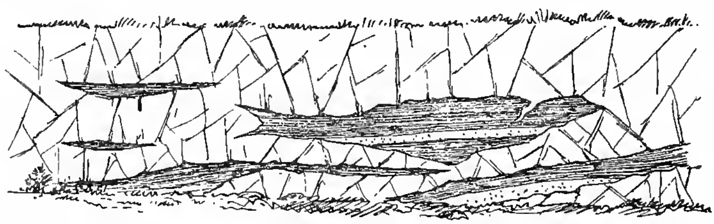


FIG. 23.—Section of Intrusive Dolerite invading Shales and Sandstones, Railway Cutting one mile south of Kirkcaldy.

into them, and caught up and enclosed large pieces of them. The accompanying diagram of the structure exposed in the railway cutting will make these features clear.

A mile further east, still another sill has insinuated itself among the strata below the Duddie Coal-seam, and may be seen in the railway cutting immediately north from Kirkcaldy Station. A mile and a half to the north-west of that section, a sill crops out at the surface at Mutton Hall and stretches thence into the Sunnyside sill already mentioned. This intrusive mass, the outcrop of which has been traced for about three miles, has made its way among the strata between the Black Coal and Parrot seams below, and the Rough and Splint coals above. Not far below the highest strata in the field a sill has been traced for nearly a mile to the north-west of Dunnikier Muir.

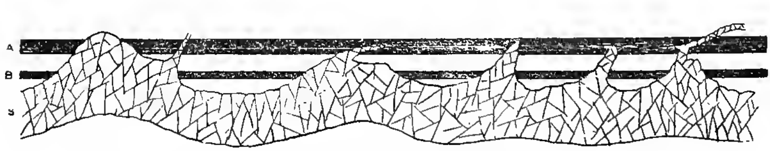


FIG. 24.—Section of Sill met with in the workings of the Panny Pit, Kirkcaldy. (Communicated by Messrs Herd, Dunnikier Colliery.)
A. The Black Coal. B. The Parrot Coal. S. The Sill.

It is obvious that such important injections of molten rock cannot have invaded the coal-field without doing it harm. While in many cases pits have been sunk through the sills and have reached the coals uninjured below, because these lay far enough from contact with the dolerite to escape, some cases have occurred, as at Kelty, where the coal has been altered into a commercially more valuable

substance, though for the most part where the intrusive material has approached near to or has actually invaded the coal, the latter has been seriously damaged or destroyed. Thus, in the Panny Pit, already alluded to, one of the sills, four to five fathoms thick, has been thrust along a line immediately below the Parrot Coal, into which, and into the overlying Black Coal, it sends tongues. (Fig. 24.)

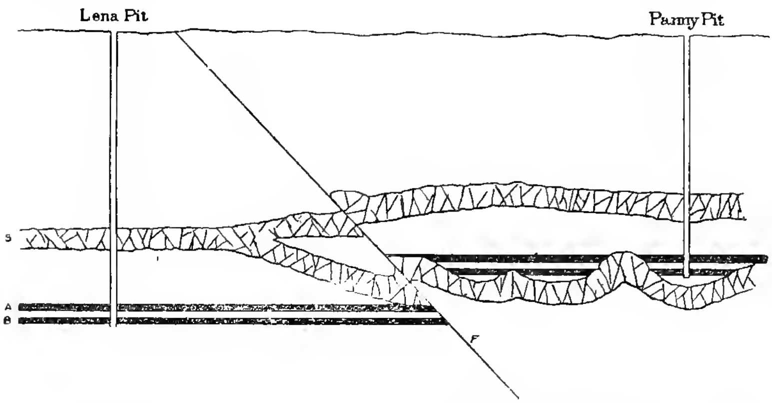


FIG. 25.—Section of Sill and Reversed Fault in the workings between the Panny Pit and the Lena Pit, Kirkcaldy. (Communicated by Messrs Herd, Dunnikier Colliery.)

A. Black Coal. B. Parrot Coal. F. Reversed Fault, six fathoms down to north. S. Sill.

Reference may here be made to another form of intrusion which has been met with in the workings in the same two seams between the Panny and Lena pits. In this case the sill appears to split into two sheets, one of which keeps above the coals, while the other lies below but invades them. (Fig. 25.) It may be remarked that a reversed fault occurs at this place which appears to cut the sills. The dislocation of the ground would thus seem to have occurred after the injection of the igneous rock.

CHAPTER XI.

The Lower Coals—continued.

V. THE MARKINCH AND BALBIRNIE FIELD.

A small disturbed basin of coal lies to the north-west of Markinch, over the estate of Balbirnie, but it appears to be now practically worked out. The seams which were met with represent the lowest of the Dunfermline series, for they are underlain by the Hosie and Hurlet Limestones. The section at the Balbirnie Engine Pit was as follows:—

	Feet.	Inches.
Surface and rock	18	–
CRAW COAL	1	6
Freestone	60	–
LITTLE COAL	1	6
"Brats and blaes"	18	–
MAIN COAL	4	9
White stone and blaes	42	–
UNDER COAL	1	10
Fireclay	12	–

The Main Coal here is believed to represent the Dunfermline Splint, while the Under Coal lies in the position of the Stinking Coal of the Dunfermline field. These two seams have been proved by bores and pits all over the Balbirnie estate. As shown on the map, they are disposed in a somewhat irregularly shaped trough, of which the south-eastern lip runs in a straight north-easterly line, the strata on that side being thrown steeply against the flank of the great anticline already described. On the north-western margin, where the angles of inclination are less, the seams are bent over a subsidiary arch, one limb trending north-westwards by Coul, the other north-eastwards, keeping to the east of Balfarg. Over this arch any bores that have been put down have failed to find the coals. Within the coal-basin the levels in the various pit-workings, as shown on the mining plans, curve about in such a way as to indicate how much the strata have been disturbed. Various igneous intrusions have still further injured the value of this little coal-field. To the west lie the huge eruptive masses that stretch up into the Lomond Hills. A sill follows the course of the river Leven from Balbirnie Mills for nearly a mile up to Auchmuty Mill, where it crosses the stream and turns northward, and where the strata that underlie it can be seen dipping to the west. Another narrower intrusive sheet lies among the steeply inclined strata near Balbirnie Mills, where it has been quarried. As will be seen from

the map, this outlying portion of the coal-bearing series is abruptly cut off to the south by the great fault which here brings the Coal-measures against the Calciferous Sandstones.

vi. THE RAMELDRY FIELD.

This isolated tract of coal-bearing strata lies a mile to the south-east of the village of Kettle, where, as will be seen from the map, it has been brought down by a large fault against the Calciferous Sandstones. It has been so much invaded by eruptive rocks that the coals in parts of the field have been rendered useless and unworkable. The seams that occur here are given in the following section of the strata :—

	Feet.	Inches.
Upper or Main Coal, with a parting in the middle one inch and a half thick	3	6
Strata	60	–
Smithy Coal	1	9
Strata	24	–
Parrot Coal, with two inches of soft coal ...	4	2
Strata	60	–

These seams are disposed in the form of the segment of a basin whereof the remaining lip circles round from Bowden Hill, on the north-east to the ridge of Parkwell, on the south-west. The out-crop of the Parrot and Smithy seams lies close to the top of the great dolerite that comes in at Parkwell. It then turns north-eastward by Coaltown of Burnturk to the flanks of another great mass of dolerite that stretches from Bowden Hill for two miles and a half to the south. The field is traversed by a dyke and fault that run between the two igneous masses from Honeyhall towards Parkwell, and on the south side of this interruption the coals come in again with a southerly dip, but their further progress in that direction has not yet been traced.

The Parrot seam south of Burnturk affords another example of a coal becoming "blind," or anthracitic, no doubt in consequence of the action of igneous intrusions upon it. Two seams of blind coal have been worked from the Burnturk and Downfield Pits in the angle between the main mass and the projecting tongue of dolerite. These were formerly supposed to lie below the Parrot Coal, but they are now regarded as more probably the Smithy and Parrot seams in an altered condition. They are worked in the southern part of the field, all that part lying to the north of Rameldry being either exhausted or too poor to be mined. There are only two pits now in use, situated to the south and south-east of Rameldry farm-house, and the coal obtained from them is almost wholly employed for burning limestone at the lime-works to the south of Pitlessie.

The exact position of these seams in the coal series of Fife has not been ascertained. They may be surmised to belong to a low platform, though the absence of the limestones here deprives us of the useful key which they furnish in regard to the stratigraphy of

the region. From Honeyhall the outcrops run southward against a broad arm of the dolerite at Devon, and a two-feet coal crops out in the streamlet to the west of Devon Common, with a dip towards N.N.W. at 5°. But nothing is known of the ground beyond. Several miles to the south-west some thin coals have been found by boring in the neighbourhood of the Carriston water-reservoir.

About a mile to the east of the Rameldry field, and on the farther side of the great sheet of igneous material, numerous shallow workings of coal may be traced around Clatto. To the north-west of the farm a shaft was sunk close to the edge of the dolerite to a depth of 32 fathoms. Two coals, 7 and 8 feet thick respectively, were found to be greatly broken up and burnt. Several old gin-pits may be observed half a mile to the east of Clatto, but no record appears to exist of them. A coal, 2 feet thick, which was formerly worked to the south of the farm is supposed to overlie the two thick seams just mentioned. A seam of parrot coal, 4 feet 10 inches thick, is said to underlie what was called the Main Coal of this field.

vii. THE KILMUX FIELD.

On the south side of the great dolerite intrusion which extends for so long a distance southwards from the Rameldry field, another small coal tract was formerly worked at Kilmux, two miles to the north-east of Kennoway. It contains the following seams comprised within a depth of 50 fathoms of strata :—

Three-foot Coal.
Four-foot Coal.
Six-foot Coal.

Instead of lying by themselves in a small basin, these seams rise at the edge of a wide tract of ground which they no doubt underlie. They abut along the north against the dolerite, from which they dip south-eastwards at an angle of 35°, but bending round with a south-westerly dip so as to run back by Shepherd's Neuk, at nearly a right angle to their previous course. In the pit close by the roadside at the 10th milestone from Kirkcaldy, the Four-foot coal was met with at 58 fathoms. A day-level runs from this pit to the stream near Burnside. A seam of splint coal, 2 feet thick, was found on the south side of the high road, 100 yards south-west from Letham Feus, dipping in a westerly direction, thus indicating a rise of the strata to the east, and a possible narrowing of the Kilmux field in that quarter. The field has not been worked for some years. A considerable amount of limestone was quarried upwards of 20 years ago in Kilmux Den, but it was eventually exhausted, when it proved to have been only a large detached and transported mass lying on boulder-clay.

viii. THE SALINE, OAKLEY, AND TORRYBURN FIELDS.

The portion of the Fife Coal-field now to be described lies on the

extreme western borders of the county, and its strata dip westwards under the higher portions of the Carboniferous system, which form the coal-field of Clackmannan. In a geological sense, therefore, the Saline, Oakley, and Torryburn ground belongs to that coal-field, rather than to that of Fife. But this tract lies well within the limits of the county, displays so fully the coal-series between the lower and upper limestones, and contains, moreover, points of such special interest, that a place must be found for it in any account of the geology of Fife.

An examination of the map will show that the tract we have now to consider forms a strip of ground which begins on the north at the Outh Hill, one of the western eminences of the Cleish ridge, and stretches in a south-westerly direction to the sea at Torryburn. If the dip and strike continued regular, this strip would be about a mile broad. Owing partly to the thick cover of superficial deposits obscuring the strata, partly to the want of evidence from borings and pit-shafts, there are parts of the strip about which little can be said. Only over three sections of its course is information tolerably full. These are the Saline, Oakley, and Torry mineral-fields. We shall take them in this order, and trace the strip of coal-bearing strata from north to south.

The Saline field differs from the others which have been described in the nature and relations of its associated igneous rocks. which will be more particularly referred to after the sedimentary strata have been discussed. At North Lethans the coals are cut off to the north by a large fault, which skirts the farm and runs thence westwards by Hillside. From this line the seams are traceable for two miles to the south and have been extensively worked. They comprise those enumerated in the subjoined table:—

	Feet.	
Index Limestone, position of this seam in the volcanic tuff at west end of Saline Hill		
Strata	30 to 40	
Four-foot Coal		
Strata	39	
Eight-foot Coal		
Strata	54	
Three-foot Coal...		
Strata	144	
Upper Ironstone		Lochgelly Ironstone, position of Possil Ironstone.
Strata	54	
Lower Ironstone		
Strata	216	
Coal (3 feet)		Jersey and Main Coals.
Thin Strata		
Parrot Coal		
Strata	80 to 100	
Five-foot Coal		
Strata	90	
Two-foot Coal		
Strata	30	
Splint or Four-foot Coal (Dunfermline Splint)		
Strata		
Hosie Limestone...		

There can be little difficulty in correlating some at least of these seams with those in the Dunfermline field immediately to the east. The lowest of the list is undoubtedly the Dunfermline Splint Coal. The Upper and Lower Ironstones represent the Lochgelly Ironstone, and occupy the position of the Possil Ironstone.

The outcrops of some of the Saline coals appear in the course of the Black Devon Water below Outh Bridge. The Parrot, for example, may be seen on a line due south from North Lethans Farm. Southward some interesting variations of the outcrops may be observed. Thus, round the volcanic neck of the Knock Hill, which has pierced them, they diverge from each other, the Parrot or Gas Coal swinging round the east side of the obstruction, while the ironstones curve round the west side, followed in the same direction by the upper coals. These latter seams plunge under the edge of the great mass of tuff that forms Saline Hill. They are cut off towards the south-west by a fault which brings down the tuff against them. This fault, where it crosses the ravine of the Saline Burn, bends round to the south-east, and breaks across an axis on which the Gas Coal crops out with an easterly dip.

The lower seams pass to the west of The Bents, and hold on south-westwards in the direction of Bandrum. But some of them must roll over and form detached basins to the east of the main outcrop, as we have seen to be the case also along the western margin of the Dunfermline field. One of these little troughs is formed by the Splint Coal to the south of the intrusive boss of Dunny Gask, to the south-east of Knock Hill. Nearly two miles further south, some of the lower coals have been worked to the east of Luscar House. The Five-foot Coal is said to have been found in a "blind" state in a pit by the side of the road that leads from the south end of Carnock Moor to the high road.

The Tuff which covers so large a part of the Saline field is generally a well-bedded deposit of volcanic detritus, which has been ejected from probably more than one neighbouring vent during the deposition of the Carboniferous Limestone series of this district. Some of these eruptions appear to have preceded the deposition of the Index Limestone, but the volcanic activity continued at least as late as the time of the Gair Limestone. As the tuffs of Saline are so closely connected with the working of the coals and ironstones, an account of them may be conveniently given here. But they will be further referred to in relation to the upper group of limestones.

The great Saline tuff has been laid open in some fine natural sections, where its characteristic features may be conveniently studied. The most northerly exposure extends for nearly a mile along the course of the Black Devon above Sheardrum. At the upper end of this section, shales and ironstones have been faulted against the tuff, which dips away from them down the stream. At the lower end, the uppermost layers of the tuff dip westwards at about 15°, and are overlain by grey shaly sandstone

nclined in the same direction at similar low angles. Where best stratified, the tuff sometimes contains calcareous layers, and on the north-west flank of Saline Hill includes a limestone which is probably the Index seam. The finely-bedded, green, granular tuff contains rounded balls of an older tuff and of pale earthy basalt. Some of the bands are much coarser in texture, enclose larger fragments, and pass into volcanic conglomerate. Here and there, however, the stratification disappears, and the rock, assuming a tumultuous, structureless condition, becomes a true agglomerate. One of the largest included fragments may be seen in the tuff immediately above where a portion of the underlying yellow sandstones appears in the stream to the north-west of South Lethans. It is an irregularly shaped angular block of black shale, measuring 18 feet long by 8 feet high.

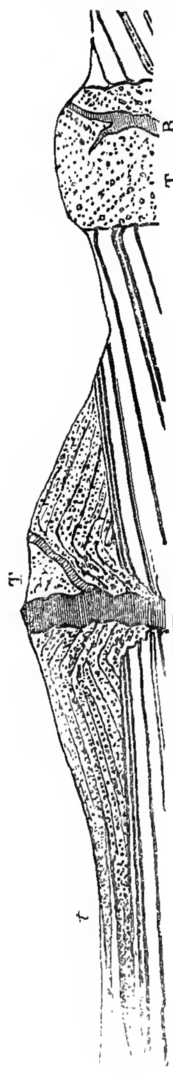


Fig. 26.—Section across the Saline Hills, Fife.
The thick parallel lines mark the positions of the seams of Coal and Ironstone of the Saline field; some of them have been worked under the margin of Saline Hill. T. Tuff of the necks. t. Tuff at a little distance from the vent, stratified and interlaminated with ordinary sediment. B. Basalt. The larger eminence is Saline Hill, the smaller is Knock Hill.

Possibly some of the coarser unarranged parts of the rock either mark the sites of vents or lie not far from these. As a corroboration of this suggestion, it should be noted that a number of dykes and veins of basalt occur at these agglomeratic centres. Some larger bosses of similar intrusive material may also be seen. The Knock Hill has already been referred to as marking the position of a vent. The Saline Hill probably stands on the site of one or two vents, round which the volcanic ashes erupted from them still partly remain, resting on the sedimentary platform on which they were deposited. The coals which have been worked under this outer envelope of encasing tuff will doubtless be found to have been destroyed around the plugs or volcanic chimneys that are believed to descend from the summits of the Easter and Wester Cairns. Another picturesque gorge in the same tuff has been cut by the Saline Burn a little above the village. A cliff of undulating well-bedded tuff forming the Raven's Craig extends between the two faults already mentioned.

These sections in the Saline district are of peculiar interest to the geologist, inasmuch as they reveal to him

the most perfect and extensive proofs in the whole region of the renewal of volcanic activity during the time of the Carboniferous Limestone series, after its cessation in the Burntisland district about the close of the Calciferous Sandstone period. We shall find other and later evidence of similar action within the time of the Carboniferous Limestone series, much further east in the Kennoway district, but on a considerably smaller scale. These Saline Hills, however, must be regarded as the typical region for this special period of volcanic activity in the western half of Fife.

The various mineral seams in the Saline field have not been continuously worked into the Oakley district, but there can be no doubt that they extend across the intervening space. About 530 yards to the east of Blairsgreen, a pit has been sunk to the Dunfermline Splint seam, which has been found at a depth of 70 fathoms. In recent years a number of bores, put down between Saline and Oakley, have passed through all the measures down to what is probably the Hosie Limestone. The lower Dunfermline seams appear to thin out in that part of the district, although their position can be fairly well identified. South-east from the farm-steading of Sunnyside, a mile and a half south-south-west from the village of Saline, the Hosie Limestone was reached at a depth of 252 fathoms from the surface. What was believed to be the position of the Dunfermline Splint Coal lay at a depth of 207½ fathoms, but the seam was only 16 inches thick. A seam of coal, 2 feet 7 inches thick, with two partings of shale and supposed to be the Mynheer seam, was met with at a depth of 179 fathoms. What was thought to be the Glassee seam occurred at 157 fathoms, but was only 16 inches thick. A splint coal, 2 feet 7 inches thick, possibly the Kinglassie Splint or Duddy Davie seam, lay at a depth of 116 fathoms. What was regarded as the Jersey Coal was pierced at 103 fathoms, but was only 3 feet 5 inches thick, including two partings. Some thin coals, interstratified with shales and ironstones, which were reached at 64 fathoms, may perhaps represent the Lochgelly Black-band ironstone. A limestone, 8 inches thick, lying among shales and fireclays, possibly the Index seam, was met with at a depth of 21½ fathoms.*

The seams which occur at Oakley and Comrie are shown in the subjoined table :—

CASTLECARY LIMESTONE = Levenseat Limestone ...	
Strata	400–500 feet.
JANET PEAT LIMESTONE = Gair or Calmy Limestone ...	about 7 feet.
Strata	10 to 20 feet.
JANET PEAT COAL	about 6 feet.
Strata	18 feet.
OVERTON or OAKLEY PARROT COAL (only 10 inches of parrot)	2 feet 1 inch.
Strata { Two coals wrought in this series, one named Cadell's Parrot Coal... ... ... }	400–500 feet.
INDEX LIMESTONE	
Strata	about 300 feet.

* The journal of this bore has been kindly supplied by the Oakley Colliery Company.

Worked at Oakley.	UPPER BLACK-BAND IRONSTONE (Oakley and Comrie) Strata	Position of Possil Seams.	about 240 feet.
	LOWER BLACK-BAND (Oakley and Comrie)		
	Strata		59 feet.
	ONTAKE COAL		
	Strata		141 feet.
	THREE-FOOT COAL		
	Strata		78 feet.
	SIX-FOOT COAL (Jersey Coal)		
	Strata		84 feet.
	FOUR-FOOT COAL (Duddy Davie Coal)		
	Strata, unknown thickness, but probably about 300 feet, in which lie the positions of the Dunfermline Splint Coal and Stinking Coal		
	HOSIE LIMESTONES		

The various seams in the Oakley field crop out to the north-west of the Forth Ironworks. The Upper Ironstone crosses the streamlet in the Bickram Wood, south of Sunnyside. The Lower Ironstone crops out 200 yards lower down and crosses over into Perthshire under the farm of Topitlaw. The Ontake Coal comes out on the bank of the burn at the Muirside sandstone quarry, while the Three-foot seam appears in the stream immediately above Comrie Bridge. These seams are powerfully affected by several large faults which traverse the Oakley field. The most northerly dislocation may possibly be a continuation of the great Loch Fitty fault, which makes the northern boundary of the Dunfermline field. It appears to enter the Oakley field in an east and west line, somewhere to the north of Blair House, and it passes into Perthshire among the ironstone pits to the north-west of Topitlaw, where it has a downthrow of 10 fathoms to the south. A much more effective fault, a little further south, runs in an east and west direction from the ironworks for half a mile west of the county boundary, when it bends towards the north-west and, passing under the Mains of Comrie, appears to unite with the fault just referred to. The throw of this dislocation is about 70 or 80 fathoms to the south, and it shifts the outcrops of the strata for about two-thirds of a mile to the east. The Ironstone is at the surface immediately to the west of the ironworks. To the south of the Oakley Station another fault brings up the Ontake Coal, which crops out at the west end of the South Oakley Cottages. At the road on the south side of these cottages, another east and west fault throws down the strata 27 fathoms to the south. The Ironstones have been found in bores and pits all over the ground to the west, and southwards to the coast at Torry. The Upper Ironstone has been reached at a depth of 90 fathoms in a pit on the Perthshire side of the county-boundary, 700 yards due south of Rennie's Walls.

An important boring (Blairhall Diamond Bore) has been made by the Coltness Iron Company about a mile west of Oakley Station and close to Rennie's Walls. The journal of this bore has been courteously communicated to the Geological Survey by the Manager of the Company, and is given at the end of the Appendix to the present Memoir. At a depth of 350 fathoms a limestone 8 feet

thick was pierced, which is probably one of the uppermost Hosie seams. Nearly 40 fathoms higher up, at a depth of 311 fathoms, a coal-seam 3 feet thick was met with, which is believed to be the Dunfermline Splint. At 295 fathoms a coal (4 feet 11 inches) with a number of partings was taken to represent the Five-feet seam. The Blairhall Main Coal (2 feet 10 inches) was met with at 92 fathoms, and a seam of Black-band Ironstone, 15 inches thick (Inzievar or Blairhall seam), about 10 fathoms higher up.

There is probably a good deal of disturbance between Longleas and the coast. A large mass of intrusive rock extends inland in a northerly direction for more than a mile from the shore at Torry to near Over Inzievar, and a smaller protrusion lies a little further west. A seam of Black-band Ironstone, 10 inches thick, crops out in the Bluther Burn, about 400 yards above Newmills Bridge, and another, three inches thick, appears at the Flour-mill immediately above that bridge.

Below these ironstones the Oakley and Saline Coals make their appearance and strike southward under the beach to Preston Island. They were formerly extensively worked here and had local names, as will be seen from the following table of them, given in descending order:—

	Feet.	Inches.
Index Limestone		
Strata	200 to 300	–
Black-band Ironstone (position of Possil Ironstone)		
Strata	about 30	–
Lowrie Graham's Coal		
Strata	130	–
Coal	3	6
Strata	50	–
Coal	2	–
Strata	30	–
Coal	–	9
Strata	90	–
Coal	9	–
Strata	80–85	–
Coal	5	–
Strata	30	–
Coal	2	6
Strata of unknown thickness, containing the position of the Dunfermline Splint Coal ...		
Hosie Limestone		

Some coals have also been worked further east between Torry and Torryburn. A seam 6 feet thick and another 4 feet crop out in the field to the west of the latter village.

CHAPTER XII.

The Carboniferous Limestone Series—continued.

III. The Upper Limestones.

Throughout the centre of Scotland the Carboniferous Limestone series terminates upward in a group of strata consisting chiefly of sandstones and shales with coal-seams, but including as their distinguishing feature certain bands of marine limestone, which in many respects resemble the limestones below the coal-bearing series. Where fully developed the group is arranged as follows:—

	Feet.
Limestone, Levenseat or Castlecary seam	4 to 16
Strata	350 to 500
Limestone (Calmy, Gair, Arden, or Janet Peat seam) ...	3 to 8
Strata	400 to 500
Limestone (Index seam)	2 to 4

As developed in the centre and west of Fife, a marked feature of this group of limestones is the association of volcanic rocks with them. The Index Limestone in this district is sometimes found lying in the midst of tuffs, as at Saline (p. 129). The Gair Limestone was deposited, while in some places eruptions were in progress. The volcanic activity, however, seems everywhere in this part of Scotland to have died out before the time of the highest or Levenseat seam.

From their comparative thinness these limestones have been less worked than those of the lower group, and they are not all seen in any continuous section in this district, though one or other of them may be detected in many natural exposures, as well as in occasional artificial openings. The Index seam, however, is visible at the surface only in one or two places, though it is met with in pits and bores.

The fossils of the Upper Limestones, though often abundant, both in the limestones and their associated shales, are on the whole less varied, as well as smaller in size, than those of the Hurlet seam, as if the conditions of life had been somewhat less favourable than they were during the accumulation of that seam.

The Index Limestone contains among its fossils numerous ostracods, such as species of *Bairdia*, *Beyrichia*, *Bythocypris*, *Bythocythere*, *Cytherella*, and *Kirkbya*; brachiopods, as *Streptorhynchus crenistria*, *Terebratula sacculus*; small lamellibranchs, as species of *Nuculana* and *Schizodus*, and the gasteropod *Bellerophon*. The complete list will be found in the Appendix (p. 248).

In the coast-section east of Pathhead, where the higher part of this group, as well as the Millstone Grit and the Coal-measures, are so well displayed, the Index Limestone is unfortunately concealed, as it is so generally elsewhere in Fife. But the two higher seams may be examined on the beach to the east of the old Castle of Ravenscraig. Above the position of the Index Limestone at this place, a thick and remarkably false-bedded yellow sandstone, with large tree-trunks, forms the promontory which runs seawards from the ruins of that castle. This sandstone, in cutting out the shales underneath it, supplies an excellent example of "contemporaneous erosion." It probably lies on the same platform as the well-known sandstone of Bishopbriggs and other quarries around Glasgow.

After passing over some further sandstones and shales in the same shore-section, we come upon the GAIR LIMESTONE, which is here composed of the following subdivisions:—

Black shale, with a large number of ironstone nodules and bands, 18 feet, passing down into
Grey calcareous shale (3 or 4 inches) with marine fossils, forming the roof of the limestone.
LIMESTONE, 3 to 5 inches.
Calcareous shale, crowded with small fossils, 8 inches.
LIMESTONE, 15 inches, made up organisms, mostly dwarfed forms.
Black shale, crowded with small ironstone nodules.

The limestone at this place has yielded a considerable number of fossils, which include *Fenestella* sp., *Discina nitida*, *Productus longispinus*, *P. semireticulatus*, *Spirifer trigonalis*, *Edmondia unioniformis*, *E. Josepha*, &c.; *Nuculana attenuata*, *Pleurotomaria monilifera*, *Narica variata*, *Bellerophon decussatus*, *B. Urei*, *B. leveillanus*, *Orthoceras sulcatum*. (For a full list see Appendix, p. 248.) This seam is here separated from the uppermost limestone by a group of about 350 feet of strata, consisting chiefly of yellow and white sandstone, with some shales and thin seams of coal. Some of the sandstones are crowded with remains of plants, and again display proofs of erosion of the underlying strata. One particularly remarkable example may be observed not many yards above the Gair Limestone, where almost every bed cuts across the laminæ of the bed below. Among the strata one noticeable member is a reddish coarse pebbly sandstone, with abundant clay-galls and fragments of fishes, which forms a cliff and runs out as a promontory east of the Dove Cot in front of the Three Tree Park of Dysart. These numerous pellets of clay were evidently one of the results of the erosion of the already deposited sediments.

On the coast-section west of Dysart the uppermost or LEVENSEAT LIMESTONE has its outcrop 200 yards to the east of the Gair seam. It is here composed as follows:—

Blue shales and shaly sandstones (lagoon or Coal-measure type).
Blue shale, crowded with marine fossils, 2 or 3 inches.
LIMESTONE, 3 feet, consisting of three bands, each mainly made up of the ossicles of small crinoids.
Blue shale, 6 inches.

LIMESTONE, 3 feet, with large cavities lined with cockscomb-barytes.
Blue shale, 8 feet, with marine organisms, especially at the base, where they abound, and the shale becomes highly calcareous.
LIMESTONE, 18 to 20 inches, crowded with fossils somewhat larger than the same forms in the limestones above.
Grey calcareous shale, 6 to 8 inches, with marine fossils, passing down into
Black highly carbonaceous shales (lagoon or Coal-measure type).

Here an interval of 18 feet of marine sediments is intercalated between two deposits of black carbonaceous sediment, which mark the lagoon type of conditions. These limestones possess the characteristic white colour of the typical Castlecary Limestone. They weather yellow, and show in their exposed surfaces well-preserved *Cauda-galli* markings, crowded crinoids, and other organisms.

This seam contains many of the same fossils as the Gair seam. A list of them will be found in the Appendix (p. 249).

Among the inland exposures of the Upper Limestones reference may first be made to those that continue the outcrop of the shore-section. The Levenseat seam has been quarried at Stenton, five miles north from Kirkcaldy. It there consists of several leaves, and its weathered surfaces disclose abundant crinoids and *Producti*, &c. About 16 feet of the seam are visible. The same limestone was cut a third of a mile further west in making a deep drain south of Caskieberran, and two thick coals were there also intersected. The westward continuation of the outcrop has been inserted on the map almost entirely from information derived from borings for minerals. Limestone has here and there been actually got at the surface, as on the farms of Manorleys and Wester Balbedie, and it was formerly worked in a quarry close to Kirkness House. There may be some doubt whether these localities do not include the outcrops of both the Gair and Levenseat seams.

To the north of the Dysart Coal-field several good exposures are to be seen of one or other of the group of Upper Limestones. One of these lies in the ravine above the village of Kennoway, where the Levenseat seam, about 6 feet thick, together with its overlying shales, emerges from under the coarse yellow sandstones and fine conglomerates of the Millstone Grit, and where also the Gair seam, 4 feet 6 inches thick, comes in its due place below Teuchat Head, carrying with it its overlying shales, one of which is a pyritous or "alum-shale." A seam of coal, which may be noticed among the yellow sandstones between them, is about three feet thick, and thirty years ago was worked by an ingoing eye from the bank. There is also a seam of poor hematite iron-ore (reddle or keel), of which a small ship-load was shipped at Leven.

Two miles to the east of Kennoway, the members of this group are partly laid open in the dell below Aithernie Castle. One seam of limestone is there visible, the precise horizon of which is not quite certain. It can hardly be the Levenseat seam, which should lie further down the stream and may be concealed under drift at the south end of the ravine. It may be the Gair Limestone or perhaps the Index seam. It is about three feet thick. Among

the sandstones above it, a coal may be seen, followed by shales and ironstones, while below it another coal-seam crops out among sandstones. To the coals of this group of strata more special reference will be made a little further on.

An interesting feature of this burn-section is the intercalation of a band of volcanic material about 130 feet thick, which lies immediately underneath the lower of the two coal-seams. This band consists of a fine red and green sandy tuff, well stratified, and dipping, like the strata above and below it, in a south-easterly direction at 15° to 25°. It includes a central zone of fine compact blue basalt. The tuff resembles some of those already referred to as occurring on the coast west of Seafield, near Kinghorn. This volcanic intercalation belongs to a remarkably persistent zone of tuff, which, beginning on the western borders of Fife, in the Saline district, is traceable eastwards to Largo and possibly further. It indicates that widespread renewal of volcanic activity, which has been above referred to as having taken place during the period of the Upper Limestones. The eruptions for the most part consisted almost entirely of discharges of ashes, though occasional streams of basalt were emitted, as in the instance now under consideration. This volcanic zone reaches its greatest development in the parish of Saline, as has been pointed out on p. 128.

It may be further remarked that in the district around Kennoway several large masses of volcanic tuff have been mapped. Some of these are no doubt necks, though it is possible that other portions of the tuff may belong to the volcanic zone just referred to. One of these masses of tuff makes its appearance at Drummaird, another forms Longside Hill, both a little to the north of Kennoway, while a third has been proved by bores at Letham, a mile further to the north-east. It cannot be conclusively shown that any of these areas of tuff are necks and show the sites of vents which were active during the Carboniferous Limestone period, still less that any one of them supplied the volcanic materials that are interstratified beneath the seam of limestone in the Kennoway Den. Further reference will be made to this subject in Chapter XVI., dealing with the intrusive rocks in the Carboniferous Limestone series and Coal-measures of Fife, when it will be pointed out that the necks undoubtedly belong to several different periods of volcanic activity.

As further evidence of the extension of the vents during this latest epoch of Carboniferous volcanic action in Fife, allusion may again be made to the section already (p. 111) cited from the brook by the roadside near Kinnaird, on the north of the Kelty Coal-field, where one or two bands of green tuff and a bed of earthy decomposed basalt, probably belonging to the persistent volcanic zone just referred to, are found associated with what may be the Index Limestone. The tuff of Cowden Hill to the north-west of Blairadam may form part of the same zone, though its relations to the Upper Limestones have not been determined. This

hill contains a plug of basalt, and not impossibly includes the actual neck or vent from which the tuff was discharged.

But it is in the west of Fife that the latest Carboniferous volcanoes have left the most abundant records of their activity. An account has already been given of the great masses of tuff in the Saline district. It was shown that these thick accumulations began to be piled up after the Saline coals and ironstones had been deposited, and that they continued beyond the time of the Index Limestone. That they lasted still longer, though in an

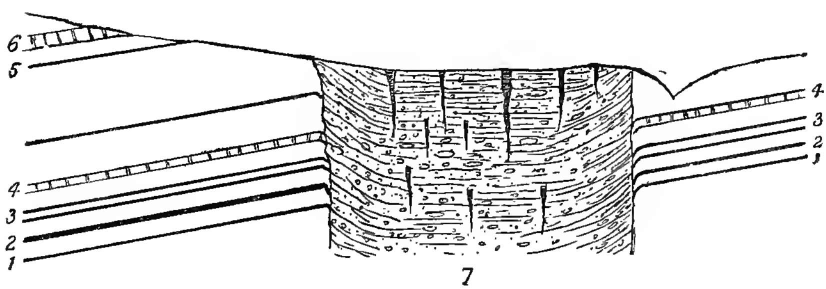


FIG. 27.—Section of Volcanic Vent near Grange, Oakley. (Mr. B. N. Peach.)

1. Three-feet Coal. 2. Ontake Coal. 3. Upper and Lower Black-band Ironstones. 4. Index Limestone. 5. Gas Coal and Janet Peat Coal. 6. Calmy or Gair Limestone. 7. Volcanic Neck.

enfeebled condition, is impressively illustrated by a section of a remarkable vent or neck which has been exposed in a cutting of the railway a mile west of Oakley, and of which the eastern edge is exposed on the border of the Survey Map (Sheet 40). It has been mapped by Mr. Peach, who constructed the accompanying section of it (Fig. 27) partly from the exposure laid open in the cutting and partly from the mining-plans of the surrounding coal- and ironstone-pits. He found it to measure 2000 feet in diameter from north to south and 1500 feet from east to west, to have been drilled through the strata, including and overlying the Index Limestone, and to be filled with crumbling clays, enclosing fragments of sandstone, shale, and coal. These clays contain many of the fossils of the next limestone (the Gair or Calmy seam), and seem to have been washed into the submarine volcanic orifice at the time that these organisms were living on the surrounding sea-floor.

CAPELDRAE COAL-FIELD.

Though coal-seams occur in the group of Upper Limestones over Central Scotland, it is seldom that they possess either thickness or quality sufficient to admit of their being profitably worked. But a notable exception to this general rule is afforded by the remarkable Capeldrae district, which lies close to the edge of the Carboniferous region beyond the east end of Benarty Hill, and

little more than a mile to the south of Loch Leven. By reference to the map it will be observed that the great arch which has been described as running through the Lochgelly field is prolonged northward, and that the Carboniferous Limestone series projects in a tongue as far as the alluvial plain of the River Leven, limited on the west side by the great boundary fault, and on the east by the Coal-measure basin of Kinglassie. This prolongation forms the Capeldrae field now to be considered.

Two features in this field deserve attention. In the first place, there is the value of the seams of coal and ironstone found here in a group of strata which is not usually distinguished for its industrial capabilities. In the second place, the commercial importance of this greater excellence of the seams has been considerably impaired by several causes, especially by intrusive igneous rocks, to which further reference will be made further on. A considerable part of the thickness of rock pierced in the bores and pits has been "whinstone."

When the Capeldrae field was first opened up great doubt was felt as to the position of its coals in the general coal series of Fife, and many conjectures were hazarded on the subject. The extensive borings and pit-workings of more recent years have proved conclusively that this field belongs to the Upper Limestone group. The Index Limestone has been met with in boring, and found to lie about 35 fathoms below the Lochore Parrot Coal and about the same distance above the Lochgelly Black-band Ironstone. The Capeldrae strata dip below another thin limestone, the outcrop of which has been chiefly traced by means of bores. The distance between this limestone and the Capeldrae Parrot Coal is said to be from 80 to 100 fathoms, of which thickness of rock 60 fathoms are made up of "whinstone." As already remarked, some doubt has been felt as to the position of this upper limestone. If it is the Gair seam there must still lie a certain thickness of strata above it until we reach the Levenseat seam, which forms the summit of the Carboniferous Limestone series. If it is itself the Levenseat seam, as seems most probable, the Gair limestone does not appear to have been yet detected here. Unfortunately, the surface of the ground is much obscured with drift. The band of limestone in question, as stated on p. 135, has been worked at Kirkness House.

The general succession of the strata in and below the Capeldrae field is given in the subjoined table, the seams worked being the Craig Coal, Capeldrae Parrot, Lochore Parrot, and Bowsebank Coal:—

	Feet.	Inches.
CRAIG COAL	4	6
Strata, of which more than half is "whinstone," one band being 174 feet thick	560	–
CAPELDRAE PARROT COAL, with cherry and foul coal ...	4	4
Strata	37	6
COAL (with 7 inches of Parrot and 2 inches of Splint) ...	2	5
Strata	18	–
CAPELDRAE IRONSTONE	1	5
Strata, including some thin coals	280	–

	Feet.	Inches.
LOCHORE PARROT COAL	2	2
Strata	18	–
COAL, Splint	3	–
Strata, with some thin coals	180	–
LIMESTONE, "Index" Seam	2	3
Strata	60	–
PARROT COAL AND BLACK-BAND IRONSTONE	2	9
Sandstones, &c....	42	
COAL	4	
Sandstone	24	–
COAL	4	3
Sandstone and "faikes"...	9	–
COAL, soft	3	–
Strata, chiefly sandstone...	40	–
BLACK-BAND IRONSTONE (Lochgelly Seam)	2	3

The Lochore Parrot Coal is composed of the following subdivisions :—

	Feet.	Inches.
Fakes and fireclay roof		
Coal, "daugh"		1
Parrot	–	11
Ironstone	–	1
Coal, "spratt"	–	5
Ironstone	–	3
Coal, "spratt"	–	3
Coal, rough		3
Fakes and sandstone pavement		

The Capeldrae Ironstone is made up of the following component layers :—

	Inches.
Black shale roof	
Black-band ironstone, hard	7
,, ,, soft	2
Fireclay	4
Black-band ironstone, soft	4
Fireclay pavement	

The Capeldrae Parrot seam is composed of the layers shown in the subjoined table :—

	Feet.	Inches.
Black shale roof		
Cherry coal	1	2
Parrot No. 2	1	8
Parrot No. 1	1	6
Fireclay pavement		

As will be understood from the map, the prolongation of the Lochgelly anticline northwards throws the strata of the Capeldrae field into a central arch, with a long trough on the west side. The shape of this trough is best seen from the mapping of the outcrop of the Parrot Coal. It will be observed that this seam, following those of the Lochgelly field, runs northward for fully a mile from the River Ore, along the west side of the arch, and, folding over near Rosewells, returns down the east side to near Glencraig, and

then, bending eastward, runs parallel with the river and dips northward under the long string of the Auchterderran sills. To the west of the arch, the outcrop of the seam turns northward with an easterly dip from the intrusive mass of Clune Craig across the dried-up bed of the old Loch Ore, so as to form a long trough enclosing the sills of Crosshill and Lochcraig. This basin extends with a tolerably uniform breadth as far as Thishalaw, where it begins to flatten and die out. The outcrop of the Capeldrae Parrot or gas-coal swings round the southern end of the Capeldrae sill, and nearly reaching Lochore House, turns to the north-east and continues that course to the far end of the coal-field at Manorleys. It then probably curves round, with first a northerly then a north-westerly dip, and passing somewhere near Kirkness House, runs up against the great boundary fault not far from Navity Hill. Borings for minerals have shown that what appears to be the uppermost or Levenseat Limestone in this part of the district bends round the end of another arch which must lie on the west side of the Capeldrae field. Hence it may be inferred that the strata below it do the same, but there does not seem to be enough of space left for any valuable extension of the Capeldrae minerals in that direction before they are cut off by the great fault.

The outcrop of the Lochore Parrot seam, which lies more than 50 fathoms below the Capeldrae Parrot, follows the western outcrop of the latter coal, and keeping to the west of Lochore House, bends north-eastwards to near Ballingry. The highest or Craig Coal crops out along the base of the line of sills by Pitcairn and Auchterderran at least as far as Balgreggie, beyond which its position has not been precisely ascertained.

Owing to several causes the working of the Capeldrae field, including the Lochore basin and the ground eastward to Auchterderran, has been rendered expensive and troublesome. The district has been disrupted by some powerful faults; it has been invaded by igneous sheets which have damaged or destroyed the minerals, and some of the coals are of poor quality, owing to an original intermixture of impurities at the time of deposition.

With regard to the faults, a glance at the map will show how greatly the field has been sliced into sections by them. Thus, immediately to the north of the farm of Capeldrae, a north-west and south-east dislocation throws the rocks 40 fathoms down to the south. The next large slip, immediately south of the old coal-pit, has the same direction of strike and throw, and displaces the strata 60 fathoms. To the north another similar fault has a throw of 25 fathoms, and others follow, one of them bringing the crop of the Parrot Coal against the great Capeldrae sill, which lies some 200 feet above it. It will be noticed that in this instance also the intrusion of molten material has preceded the general faulting of the coal-field, for the sill itself has been dislocated by the faults.

Though numerous masses of igneous rock are shown upon the map as having been intruded into the rocks of this field, they

probably do not include all that reach the surface, for some may be concealed under superficial deposits, and they certainly do not embrace all that have been injected among the strata underneath. They are of two kinds. In the first place, several tracts of volcanic tuff have been met with, which doubtless form part of the persistent volcanic zone among the Upper Limestones, and which are not improbably connected with, if they do not themselves mark the sites of, volcanic necks. One of these areas lies at Kildounies Hill, a little to the north-west of Lochore House. Another patch has been found in a boring immediately to the west of Ballingry Church. In the second place, and far more abundantly, come the sills of dolerite and basalt. Where these have been injected among the strata at a sufficient distance above or below the coals or ironstones, they have not injured the commercial value of these seams. But where they have touched or come too near the minerals, there has been a more or less complete destruction of that value. In 1888 the Capeldrae part of the field was abandoned, as the water had risen so seriously in the old and extensive workings.

In the Lochore part of the field, which has been proved by crop-mines and shafts, the successful working of the minerals has been much hindered by the occurrence of many "troubles" and "wants," where the seams were either imperfectly deposited at first, or have since been broken up by small faults. In the Rosewells portion of the field, the quality of the Parrot Coal was found to be excellent towards the south, but to fall off in value to the north around Flockhouse, owing to the appearance in it of abundant coprolites and "clay-galls," whereby its gas-producing properties were seriously reduced. Here a second gas-coal, known as the Wee Parrot, lying 14 fathoms below the Capeldrae seam, has been worked to a small extent on either side of the anticlinal fold, along the centre of which it crops out.

The eastward prolongation of the Capeldrae Parrot seam to Auchterderran has been proved by numerous borings. But in almost every case it has been found to be either "burnt" through the effects of the igneous rocks, or it has gone into the poor condition known in mining language as "wild parrot." In the same part of the field the Craig Coal, which there lies in some places, as at Pitcairn, between two sills, has also been found to be burnt, though it was formerly worked to a small extent on the east side of Balgreggie.

In the Lochgelly and Dunfermline fields, the upper limestones appear to have been entirely removed by denudation even from the deepest parts of their basins. At least, these seams have not been recorded in any of the borings or pit-shafts with which the Geological Survey has become acquainted. That they once covered the whole of the strata in that wide district is shown by their reappearanee to the west, when the westward dip of the strata beyond Saline, Oakley, and Torryburn allows them to take their usual place. The Index Limestone crops out in the Bluther Burn above the coals and sills at Torryburn. It is

found again in the stream to the west of Oakley Station, and further north near Sunnyside, and again close to Saline.

The Gair or Janet Peat Limestone reappears in the same part of the district, while the Levenseat Limestone has likewise been traced by a number of exposures along the west side of the Carboniferous Limestone region, of which it forms the boundary from near Cult Hill on the north to the shores of the Firth west of Culross.

CHAPTER XIII.

The Millstone Grit.

THE next division of the Carboniferous system, known as the Millstone Grit, is not well seen in Fife, except on the coast, and, owing to the peculiar geological structure of the county, is confined to a comparatively restricted area. As the name denotes, this series of strata consists principally of coarse sandstones. In some parts of Central Scotland, where it comes immediately to the surface, it forms tracts of barren moor, and has been named the Moor-rock. But in Fife its inland extension is so generally buried under drift that it only comes there to the surface in the water-courses. By far the best section of it, not only in Fife, but in Scotland, is to be seen along the shore of the Firth of Forth between Pathhead and Dysart, where every member of the series is laid open to view. The section that has been cut by the River Esk in the Midlothian Coal-field, between Roslin and Lasswade, is much longer and more picturesque, but it does not supply so complete an exposure of the whole strata that form the Scottish Millstone Grit as is done by the coast-section in Fife.

Beginning on the beach, 400 yards due east from the promontory of the Ravens Craig, we start from the summit of the Carboniferous Limestone Series marked by the Levenseat Limestone, and pass over a continuous sequence of sandy strata, dipping eastwards at 25° to 30° for about 500 yards, when black shales and thin coals make their appearance. No very clearly marked line can be drawn either at the base or the top of this sandy series to separate it from the strata below and above it, for they graduate insensibly into each other. But measuring from the limestone seam as a base, it will not be an exaggeration to set down the thickness of the Millstone Grit here as about 700 feet.

Immediately above the shales that overlie and belong to the Levenseat Limestone sandy strata begin to make their appearance, but intermingled with shaly layers, showing how gradually the arenaceous replaced the argillaceous sediment. After about 40 feet of such intermingled materials the sandstones set in, and continue to form practically the whole of the strata for a depth of more than 250 feet, though an occasional band of shale may be observed among them. They are then interrupted by from 30 to 40 feet of argillaceous sediments, comprising, besides shales and fireclays, one or two thin seams of coal and several layers of shaly sandstone. Another group of sandstones follows this central zone of shaly and carbonaceous bands, for a thickness of more than 250 feet. Above

these the arenaceous sediment becomes more and more interleaved with shales and fireclays, while the sandstones themselves become increasingly shaly, until the ordinary type of Coal-measure strata is entered.

Many of the sandstones are more or less blotched or stained red. This colouring seems rather a subsequent effect than an original tint taken at the time of deposition. Its frequent occurrence all over Fife suggests the possible former extension of some red formation across the region, though all trace of that formation has been since removed. This question will be more fully discussed in the Memoir on Eastern Fife, where the materials for its consideration are more ample. The texture of the sandstones of the Millstone Grit is sometimes tolerably coarse, though of those exposed along the shore hardly any deserve the name of conglomerates. The predominant ingredient is quartz in pea-like granules, varying up to a quarter of an inch or more in diameter. These, though mostly water-clear, are interspersed with grains of the blue opaline variety so abundant in the Lewisian gneiss of the north-west of Scotland. The grains are in general not well rounded, but rather angular. Associated with them there is usually a smaller proportion of decayed felspar and some white mica flakes. In some bands, where the proportion of felspar increases, the stone weathers into a kind of sandy clay. One of the coarsest bands lies near the top of the series. As usual, it is spotted red and contains grains of quartz, more or less angular in shape, which occasionally measure half an inch across.

It will be seen from the map that the Millstone Grit strikes inland from the coast, lessens in its angle of dip so as to broaden in its outcrop, and holds on as a border or frame to the Dysart and Leven Coal-field. Between the shore and the River Leven near Markinch hardly any openings in this frame are to be met with. To the south of Markinch Station, the upper part of the sandstones has been quarried above Parley Brae. The strata are there interleaved with black shales, include a thin basalt-sill, and dip to the east at 60°. By a large fault which runs from Markinch to the sea the outcrop of the strata is shifted about two miles to the east. On the north side of this interruption a good section of the series may be seen in the Den of Kennoway above the outcrop of Levenseat Limestone already alluded to. Coarse yellow and white sandstone, reddish sandstones, and fine quartz-conglomerates have there been eroded by the stream. They are pierced by a small volcanic neck of tuff, which proves the continuance of volcanic activity here at some time later than the Millstone Grit. Another powerful dislocation, which runs from beyond Kennoway to the coast, again shifts the outcrop of the Millstone Grit for more than a mile and a half. The grits are next seen in the Scoonie Burn near Blacketyside, where coarse pink sandstone and fine conglomerates have been laid bare in the water-course. Beyond this point the Millstone Grit does not appear at the surface further eastward, inasmuch as another of the series of great dislocations cuts it off by bringing down the Coal-measures against the Carboniferous Limestone Series

Returning now to that part of the inland frame of Millstone Grit where the outcrop is broadest, we may note that this widening arises not merely from the lessening of the angle of dip, but also from the fact that the strata are here folded over the great anticline which runs from Burntisland to beyond Markinch. The Levenseat Limestone which fixes the base of the Millstone Grit occurs at Stenton, and has been traced by means of borings to Inchdairnie Park. The Millstone Grit no doubt turns westward here also on the west side of the anticline and dips under the Kinglassie Coal-field. But the ground is so obscured with drift that in the absence of reliable information the series has not been indicated on the map beyond Kinglassie. There can hardly be any doubt, however, that it continues to the south-westward as a border round the little coal-field, though possibly in a locally attenuated condition.

Towards the western boundaries of Fife the Millstone Grit reappears in its proper place above the Levenseat Limestone, and broadens out over a wide tract of country on the east side of the Clackmannan Coal-field, where its outcrop at one part of its course attains a width of six miles.

CHAPTER XIV.

The Coal-measures.

Following conformably on the top of the Millstone Grit, as above stated, comes the thick and important division of the true Coal-measures. In Fife, as in the rest of Scotland, it is easily capable of a two-fold grouping. The lower and main portion of the series consists of a succession of white and yellow sandstones, dark grey and black shales, and other sedimentary strata which include a number of workable coal-seams. The upper subdivision is composed mainly of red and purple sandstones, shales, and clays, with only a few thin coal-seams. Each of these two groups will be separately described.

The recent researches of Mr. Kidston among Carboniferous fossil plants indicate from the evidence of the fossil flora that the lower or coal-bearing group of Scotland is probably the equivalent of the lower division of the Coal-measures of England, while the upper or red group represents the English Middle Coal-measures. There does not appear to be any equivalent in Fife, or indeed in Scotland, so far as at present known, of the highest division in England, so well displayed in the Bristol and Somerset Coal-field.

At the outset it is deserving of remark that the development of the Coal-measures in Fife, though not more extensive or better characterised than in other parts of central Scotland, offers this great advantage for observation and study, that it is exposed along a continuous coast-section, where almost every individual stratum may be seen and measured. For a distance of seven miles this section continues to display the stratigraphical succession on the beach and along a range of low cliffs. Hence both for the geologist and for the mining engineer who may wish to familiarise himself with the typical characters of Coal-measure strata there are few such natural sections in Britain. Certainly there is none to be compared with it in Scotland. The Clyde and its tributaries have often cut highly picturesque gorges through the Lanarkshire Coal-measures, as the Esk has done through those of Midlothian, but while supplying much interesting and important geological detail, they fail to afford a continuous and complete presentment of the whole of the highest division of the Scottish Carboniferous system.

I. Lower or Coal-bearing Group.

This group of strata is composed mainly of sandstones and shales, with a number of seams of workable coal. It has a total thickness of about 1750 feet.

The flora of the Fife Coal-measures agrees with that obtained from the corresponding strata in other parts of the country. It includes such well-known and characteristic plants as *Cordaites borassifolius*, *Cordaianthus* (*Antholites*) *Pitcairniæ*, *Calamocladus* (*Asterophyllites*) *equisetiformis*, *Calamites Suckowii*, *C. varians*, *Mariopteris muricata*, *Neuropteris gigantea*, *N. heterophylla*, *Sphenopteris latifolia*, *Lepidodendron ophiurus*, *Trigonocarpus*.

The fauna assumes two types.* Throughout the Coal-measures the common lamellibranchs are forms of *Carbonicola* (*Anthracosia*), *C. acuta*, *C. aquilina*, *Naiadites* (*Anthracoptera*), and *Anthracomya*; the usual annelid is *Spirorbis pusillus*; the ostracods comprise one or two species of *Carbonia*; fishes are represented by *Megalichthys Hibberti*, *Strepsodus sauroides*, *Diplodus gibbosus*, and species of *Ctenodus*, *Cœlacanthus*, *Rhizodopsis*, *Acanthodes*, *Pleuracanthus*, &c.; amphibians by *Loxomma Allmanni* and *Anthracosaurus Russelli*. This is the prevalent and typical fauna of the true Coal-measures, and has been regarded as indicative of somewhat shallow, brackish or estuarine waters, in the lagoons of which the matted vegetation grew and accumulated which now forms the coal-seams.

Mr. Kirkby, however, has observed, as had previously been found in Lanarkshire and in various parts of England, that on at least one platform in the Coal-measures of Fife there is a recurrence of the more obviously marine fauna of the Carboniferous Limestone. Above the highest of the workable coals, and not far from the top of the group of strata now in question, he detected, in a band of black, brown, or purple shale, specimens of crinoid stems, *Lingula*, *Discina*, *Productus semireticulatus*, *Aclisina* (*Murchisonia*) *striatula*, *Bellerophon Urei*, *Orthoceras*, and *Discites*, together with various fishes (p. 250). The recurrence of these Carboniferous Limestone forms points to the occasional access of the opener sea to the more land-locked lagoons in which the Coal-measures seem to have been for the most part deposited.

As shown upon the map, the lower group of the Coal-measures of Fife occupies a compact and connected area, which extends along the coast from a point a little west of Dysart eastwards to Wemyss Castle—a distance of nearly three miles. Thence it stretches inland to Markinch, and returns to the coast north-east of Leven. Like the Millstone Grit and Carboniferous Limestone, the Coal-measures fold over the great anticline that runs by Markinch, and extend as a strip on its northern side, expanding westwards to form the detached little coal-basin of Kinglassie. They do not reappear

* See an interesting and important paper by Mr. J. W. Kirkby, who first established this point for the Fife coal-field. *Quart. Journ. Geol. Soc.*, xliv. (1888), p. 747. The facts given in the text are taken from this paper.

further to the west until, beyond the limits of the county of Fife, they enter the Clackmannan Coal-field.

i. THE DYSART, WEMYSS, AND LEVEN COAL-FIELD.

Under the title of the Dysart, Wemyss, and Leven Coal-field may be included all the area of the coal-bearing part of the Coal-measures from Dysart to Wemyss on the coast, inland to Markinch, and northwards to Durie and Leven. Within this compact area there are numerous collieries, with sometimes tracts of still little explored ground between them. But the whole forms really one coal-field, which has long been known under the name of its chief town, Dysart.

A generalised summary of the coal-seams in the field, with the average thicknesses of intervening strata, is given in descending order in the subjoined Table:—

	Feet.	Inches.
Strata below the Upper barren red group of the Coal-measures	280	–
In these strata at a height of 210 feet above the Barncraig Coal lies the band of *Lingula*-shale above referred to.		
WALL-COAL	3	6
Strata	100	–
BARNCRAIG COAL	6	–
Strata	85	–
UPPER COXTOOL COAL	2	6
Strata	30	–
LOWER COXTOOL COAL	3	–
Strata	36	–
DEN COAL	2	–
Strata	120	–
CHEMISS COAL	9	
Strata	60	–
BUSH COAL	3	9
Strata	350	–
PARROT COAL	3	3
Strata	37	–
WOOD COAL	3	–
Strata	37	–
EARL'S PARROT COAL	2	
Strata	47	–
BOWHOUSE COAL	7	
Strata	42	–
BRANKSTONE COAL	2	6
Strata	57	–
MORE COAL	1	9
Strata	80	–
MANGIE COAL	2	4
Strata	22	–
SANDWELL COAL	1	3
Strata	200	–
DYSART MAIN COAL	19	2
Strata	75	–
SEVEN-FOOT COAL	6	7
Strata to top of Millstone Grit	200	–

Before proceeding to consider more in detail the composition and distribution of these coal-seams it may be convenient to take notice

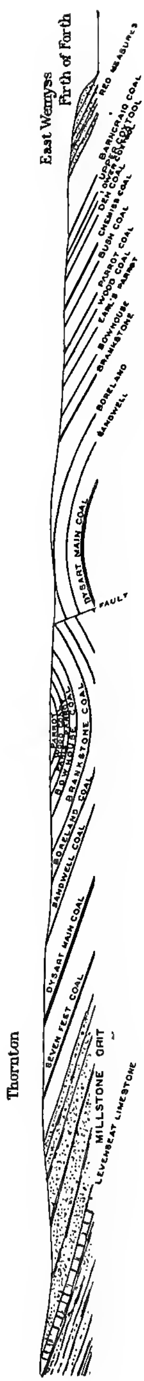


FIG. 28.—Section across the Dysart Coal-field from near Thornton on the west to East Wemyss on the coast.

here of some important features in the general structure of the field, more especially as these must be understood before the meaning of an apparently anomalous disposition of the outcrops can be appreciated.

Although the coast-section supplies a fairly complete and unbroken section of the strata, it will be seen from the map that this regularity disappears in the inland part of the district, that the superficial breadth of the strata greatly expands, and that instead of the single outcrops that emerge on the coast, some of the seams have two outcrops. This structure arises from a combination of plication and dislocation. Less than a mile from the shore a double fold, complicated by a powerful fault, begins to make its appearance. The outcrops of the lower coals in this group, that is, those up to and including the More Coal, continue their normal direction towards N.N.W. But the higher coals, from the Brankstone seam upwards, turn off sharply to the north-east, and the space between the main outcrops of the two groups continues to widen, until two seams which are only distant from each other about 1200 yards on the shore are separated by an interval of more than two miles. If there were only curvature in question, and if we could strip off all the overlying cover of drift, it would be seen that the Coal-measures have here been ridged up into an anticlinal and a synclinal fold, the axes of which run in a N.N.E. and S.S.W. direction. In consequence of this plication some of the upper coals would be found to lie in a basin or trough on the west side, and some of the seams below them to crop out along the sides or crest of the arch. Unfortunately the ground is too much concealed by superficial deposits to permit an actual sight of this interesting structure, which has only been made known by the bores and underground workings of the coal-pits.

From the same sources of information we learn that the anticline has been ruptured by a powerful fault which still further complicates the structure (Fig. 28). The position of this fault has been proved in the southern part of its course between Boreland and Cowdenlaws. It must run on in a nearly

northerly direction, probably increasing in magnitude as it goes, until it ends off against the great fault between Markinch and the sea. The effect of this dislocation is to throw down the strata on its western side. Hence the lower coals, which run continuously from the sea to Markinch along their normal outcrop and ought to be deep underground in the centre of the coal-field, are actually brought up to the surface on the east side of the fault, and though it has not been actually identified, there is reason to suppose that at least the upper part of the Millstone Grit may also come up above ground towards the valley of the Leven.

While the dislocation of the coal-field is under description, reference may be made to the other more important faults by which the coal-seams have been displaced. One of these passes in a south-easterly direction through Earl's Seat, a mile to the east of Thornton Junction, and shifts the outcrops of the Seven-foot and Dysart Main coals about 400 yards, with a downthrow to the west. Another still more powerful fault strikes from this last one near Earl's Seat, and runs in an E.N.E. direction to the sea at Broadhill Rocks, near Buckhaven. It is said to have a southward downthrow of 60 or 70 fathoms, which increases eastward to 100 fathoms. It will be seen from the map to shift the outcrops of the coals westwards for fully three-quarters of a mile. Another fault, lying somewhat further north and running inland from a little south of Methil by Muiredge and The Maw, has a downthrow to the south of 30 to 45 fathoms. Further north lie the great parallel faults already mentioned as cutting the coal-field and the Millstone Grit into slices, with a persistent downthrow to the south.

We may now examine in further detail the succession of the coal-seams enumerated in the Table on p. 148. A few seams of coal only an inch or two in thickness come below the SEVEN-FOOT SEAM, which is the lowest of the workable coals. At the Sweet Dub Pit, Gallatown, Dysart, that seam had the following composition :—

	Feet.	Inches.
Hard grey stone roof		
Coal	1	3
Stone	–	1
Coal	2	4
Fireclay	2	6
Coal, rough	1	8
Coal, Parrot	–	8
Coal, rough		8
	9	2
Shale pavement		

This seam is overlain by about 10 or 12 fathoms of strata including at the base about 7 feet of shales and thin clay-band ironstones, and nearly 50 feet of sandstones towards the top. Then comes the DYSART MAIN COAL—the thickest seam in any part of Fife. This coal is subject to local variations in the number and

arrangement of its component bands. In the Frances Colliery, a mile and a half north of Dysart, it is constituted as follows:—

	Feet.	Inches.
Roof-coal (coarse)	4	–
Stone	–	1
Spar Coal	1	8
Spar Stone	–	1
Head Coal	1	8
Clean Coal	1	9
Stone	–	4
Splint Coal	–	10
Stone	–	3
Nether Coal	3	6
Stone	–	1
Ground Coal	3	7
Stone	–	9
Thief Coal	5	
	23	7

The top and bottom of the coal are not usually worked. As the seam runs inland towards the north and north-east it becomes thinner. At Lochhead, two miles to the north-east of Dysart, it has the following structure:—

	Feet.	Inches.
Shale roof		
Coal	2	–
Stone	–	2
Coal	1	6
Stone	–	3
Coal	3	6
Stone		4
Coal		11
Stone	–	4
Coal	7	–
Stone	–	1
Coal	3	–
	20	1
Shale pavement		

Thus in a distance of two miles there is an appreciable diminution in the proportion of coal and increase in that of the sedimentary partings. The coal continues to become thinner both to the north and east. In a boring little more than a mile to the north-north-west of Lochhead, the seam was found to be only 10 feet thick. Again at Cameron Bridge, three miles to the north-east of Lochhead, its thickness was also 10 feet. The seam has not been worked to the east of the Isabella Pit (Muiredge Colliery), and nothing appears to be known of its occurrence in that direction, nor whether any of the workable seams below the Parrot Coal are available in that part of the field.

The Dysart Main Coal from the coast-line inland to Markinch has all been worked out down to the water-level. It was found to run on steadily along the line of outcrop traced upon the map. The present workings lie to the east, where some of the coals are won

under the sea. At Wells Green the Dysart Main Coal was reached at a depth of 83 fathoms, and the Parrot seam was also passed through.

Three or four comparatively unimportant seams of coal, which have received local names, are intercalated in the 65 fathoms of strata that lie between the Dysart Main seam and the next thick seam, which is known as the BOWHOUSE COAL. In the Victoria Pit, West Wemyss, this seam was found to consist of the following members:—

	Feet.	Inches.
Shale roof		
Coal		4
Shale	–	6
Coal	7	–
Shale	–	8
Coal	–	4
Shale pavement		

This coal must be present in the trough above described as lying on the west side of the field, but its limits there have not been ascertained. Its normal outcrop stretches from the coast near Dysart to the large fault that runs out to sea near Buckhaven, and the seam is found again on the north side of that dislocation.

The EARL'S PARROT COAL in the Victoria Pit, West Wemyss, has the arrangement shown in the subjoined Table:—

	Feet.	Inches.
Shale and bands (roof)		
Coal, Parrot	1	2
Coal, rough	1	2
	2	4
Shale pavement		

The WOOD COAL lies about 64 feet above the Earl's Parrot seam and has a thickness of three feet. From the shale and sandstone bands forming the roof of this seam at the Pirnie Colliery, Leven, Mr. Kirkby has obtained a number of fossils, of which he has been so good as to supply the following list:—*Cordaianthus* (*Antholites*) *Pitcairniæ*, L. & H.; *Alethopteris lonchitica*, Sch.; *Calamocladus equisetiformis*, *Calamites*, sp., *C. Suckowii*, Brong.; *C. approximata*, Brong.; *Carpolithes sulcosa*, L. & H.; *Cordaites borassifolius*, Sternb.; *Mariopteris muricata*, forma *nervosa*; *Myriophyllites gracilis*, *Neuropteris gigantea*, Sternb; *N. heterophylla*, L. & H.; *Sphenopteris latifolia* ?, L. & H.; *Sphenophyllum*, sp.; *Trigonocarpus*, sp.

The Parrot Coal in the section obtained from the same pit is composed as follows:—

		Feet.	Inches.
	Sandstone	58	–
	Shale	4	–
The Parrot seam.	Black Shale	–	4
The Parrot seam.	Parrot Coal	–	5
The Parrot seam.	Black Shale	–	4
The Parrot seam.	Stone	–	2
The Parrot seam.	Coal	2	–
	Brown Stone	1	–
	Coal	–	3
	Shale	2	9

As shown upon the map, a small basin of this seam has been detected on the west side of the anticline. The main outcrop begins on the shore immediately to the west of Blair Point, and runs on with the other seams in a continuous line until it strikes against the Earl's Seat-Buckhaven fault.

Mr. Kirkby has kindly furnished the following list of fossils found by him in the Parrot Coal at Pirnie Colliery, Leven:—

AMPHIBIA.—*Anthracosaurus Russelli*, Huxley; *Loxomma Allmanni*, Huxley.

PISCES.—*Acanthodes*, sp.; *Cœlacanthus elegans*, Newberry; *Sphenacanthus*, sp.; *Ctenodus*, sp.; *Diplodus gibbosus*, Ag.; *Helodus*, sp.; *Megalichthys Hibberti*, Ag.; *Pleuracanthus lævissimus*, Ag.; *Rhizodopsis sauroides* (Williamson); *Strepsodus sauroides* (Binney); Coprolites.

MOLLUSCA.—*Anthracomya*, sp.

CRUSTACEA.—*Carbonia fabulina*, Jones & Kirkby; *C. rankiniana*, J. & K.

ANNELIDA.—*Spirorbis pusillus* (= *S. carbonarius*, Murch); worm tracks.

PLANTÆ.—*Cordaianthus Pitcairniæ*, Lindley & Hutton; *Calamites*, sp.; *Cordaites*, sp.; *Halonia*, sp. (=*Lepidophloios*, sp.); *Lepidodendron*, sp.; *Sigillaria*, sp.—encrusted with *Spirorbis pusillus*; *Sigillaria*, sp.; *Stigmaria ficoides*, Brong.; Macrospores.

Mr. Kirkby has also been so good as to supplement his list with some notes in regard to the occurrence of the organisms. "These fossils," he remarks, "were found in all parts of the seam and in the black shale or 'rhums' overlying it, though oftenest in the 'brown stone' or black-band in the centre. The plants were of much rarer occurrence than the fish-remains—*Stigmaria* excepted. Of the latter, those of *Strepsodus sauroides* and *Megalichthys Hibberti* were found most frequently, though nowhere plentiful. The remains of *Strepsodus*—bones and plates of the head, with the teeth in the jaws, vertebræ, and scales, all more or less out of place, though close together, have been traced over surfaces of the brown stone for five or six feet, thus indicating individuals of considerable magnitude. Some of the *Megalichthys* have also evidently been big fish, from the size of the scales and head-plates, and from the extent of surface which their fragmentary remains cover. In two instances nearly perfect examples of small *Megalichthys* were found—about 12 inches in length.

"The amphibian remains were rare, and comprised portions of the head, ribs, and vertebræ.

"With the exception of the *Stigmariæ*, the plants were evidently all of them drifted specimens, the *Sigillariæ* being in some cases encrusted with *Spirorbis pusillus*. Rather curiously, examples of that usually rare species *Cordaianthus* (*Antholites*) *Pitcairniæ* occurred fully as often as any of the others. Ferns were never found. The *Stigmariæ* were always in the upper portion of the seam and in the rhums above. They were not drifted specimens, but with rootlets attached to the roots and spread out on each side, as though having grown where found. In fact, they most likely came down into the coal as roots of the *Sigillaria* or other trees that existed during the deposition of the overlying shales, and are thus not exactly contemporaneous with the fossils associated with them."

The CHEMISS COAL has a thickness of nine feet, and lies between a shale pavement and roof. It is now worked under the sea. The level driven in it in the workings at Wemyss lies 90 fathoms below high-water mark. At the Rosie Pit, half-way between East Wemyss and Buckhaven, the seam was found at a depth of 98 fathoms, dipping towards E.S.E. at 10°. North of the Earl's Seat-Buckhaven fault this seam is worked in the strip of ground that intervenes between that dislocation and the Muiredge north fault at depths of from 70 to 80 fathoms, and again to the north of the last-named fault between Methilhill, where it crops out, and the sea. This coal being now the chief workable seam in this part of the field is locally known as the Main Coal.

From the shale forming the roof of the Chemiss Coal at Muiredge Colliery, Buckhaven, Mr. Kirkby has collected *Alethopteris lonchitica*, Sch.; *Calamites*, sp.; *Lepidodendron elegans*, *L. longifolium*, Sternb.; *Mariopteris muricata*, forma *nervosa*, Sch. (*Spirorbis pusillus* attached); *Sphenopteris*, sp.; *Trigonocarpus*, sp.

In the district around Leven the Chemiss or Main Coal is succeeded (after an interval in which the Den Coal is represented) by the SIX-FOOT and EIGHT-FOOT seams, which no doubt represent the Coxtool and Barncraig seams of the Dysart district. These seams, together with the Chemiss, are worked in the Methil Pit. Further on, about 300 yards to the north-east of Kirkland Farm and 100 yards south of the Leven Road, a sinking has been put down by the Fife Coal Company by which the same three seams are worked. The Chemiss Coal is there 144 fathoms below the surface.

The same seams crop out on the north side of the Leven River between Kirkland and Banbeath, until they abut against the large fault that strikes out to sea at Scoonie Links, and has a throw of 130 fathoms. On the north side of that fault, but at some distance eastward, their outcrops have again been traced. At the Durie Colliery the Main Coal was found at 60 fathoms, the Six-foot seam at 33, and the Eight-foot at 28 fathoms. In the new Scoonie Pit, which is close to the first milestone on the high road from Leven to St. Andrews, the Chemiss seam lies at a depth of 99 fathoms.

From waste-heaps of the roof of the Six-foot or Upper Coxtool Coal at the East Newton Pit, near East Wemyss, Mr. Kirkby collected *Alethopteris lonchitica*, *Lepidodendron longifolium*, Sternb.; *Lepidostrobus*, sp. (large); *Mariopteris muricata*, Schl; ditto var. *nervosa*; *Neuropteris auriculata*, Brong.; *Neuropteris*, two species; *Eremopteris artemisiæfolia*, Sternb.; *Sphenopteris latifolia*, Brong.; *S.*, sp.; *Sphenophyllum cuneifolium*, and other species.

The same diligent and accurate palæontologist has obtained from the roof of the Eight-foot Coal—consisting of dark shale and ironstone bands—at the Durie and Leven Collieries, the following series of organisms:—*Carbonicola* (*Anthracosia*) *acuta*, Sow.; *C.*

aquilina, Sow.; *Anthracomya Wardi*, Salter; *Anthracoptera carinata*, Sow.; *Megalichthys Hibberti*, Ag.—scales and teeth; *Strepsodus sauroides* (Binney)—teeth; *Carbonia fabulina*, J. & K.; *Spirorbis pusillus*, Murch.; along with stray plant-remains.

In furnishing the Geological Survey with these lists Mr. Kirkby accompanied them with the following notes on the mode of occurrence of the fossils, and thus supplied information that could only be obtained by an observer long resident on the ground:—

"The *Carbonicolæ* (*Anthracosiæ*) and other shells occur in great abundance at the last-named pits, as well as at others at West Wemyss, East Wemyss, Muiredge, Denbeath, and Scoonie where the coal (Eight-foot) is or has been wrought. They form, in fact, a well-marked and constant horizon in the Fifeshire Coal-measures.

"The other coals worked in the Wemyss and adjoining coal-fields have roofs either almost barren of fossils or contain only plant-remains. Sometimes the latter fossils are fairly plentiful and well preserved, though never constantly so, so as to characterise the coal throughout its range. For instance, the roof of the Upper Coxtool, at the East Newton Pit, was full of finely preserved ferns and other plants, whereas further to the east, at the Muiredge and the Leven Pits, where the same coal is now wrought under the name of the Six-foot, there is not a fossil worth collecting. In the same way there are areas in the shale forming the roof of the Chemiss Coal at the Muiredge, Leven, and Durie Pits that are fairly full of plants, though such are exceptional. The roof of the Wood Coal contains good plants in moderate abundance at Pirnie Colliery, along with numerous upright stools of trees—the 'pot-bottoms' of the colliers. In fact, plants in this district occur in much the same partial way as in other coal-fields, being local in their distribution rather than persistent and general over wide areas, as in the case of the 'mussel-bands' of the *Anthracosiæ* and allied shells.

"Another well-marked horizon forming the roof of a coal is that lying immediately above a thin seam (which is never wrought) high in the series, and just below the base of the red beds. This shale contains a suite of marine fossils belonging to *Discites*, *Bellerophon*, *Murchisonia*, *Productus*, *Lingula*, and other genera." This is the horizon already referred to on p. 147 as containing marine shells. It occurs at a height of 210 feet above the Barncraig Coal. It is a carbonaceous black, brown, or rather purple shale, and encloses flat concretions or galls of soft red ironstone which enclose well-preserved *Lingulæ*. Its outcrop may be seen on the beach a little to the east of Wemyss Castle, also 500 yards to the north of East Wemyss in the ravine known as Wemyss Den, which is the channel of the Kingslaw Burn. The seam was passed though in sinking the shaft of the Denbeath Colliery between Methil and Buckhaven.*

It has already been mentioned that in the case of the Dysart Main Coal a perceptible diminution of the coaly part of the seam, with

* For fuller details see Mr. Kirkby's paper already cited on p. 147.

a corresponding increase in the accompanying partings of sedimentary material, could be traced in the eastward extension of the workings. But as the rocks have been followed still further in the same direction a diminution in the thickness of the whole group of strata has been ascertained. Thus near Wemyss the thickness of measures lying between the Chemiss Coal and the base of the overlying red group is about 500 feet. At Muiredge, little more than a mile to the east, this thickness has diminished to about 325 feet. Still further towards the north-east, in the Leven section, it appears to be not much more than 250 feet, while beyond that point it has shrunk at Durie to only about 175 feet. That this diminution is not due to any unconformability or overlap of the red upper measures on the coal-bearing series is shown by measurements of the thickness of strata between two such well-known seams as the Chemiss and Eight-foot or Barncraig. This intercalated group of sediments is about 230 feet thick at Wemyss. It gradually lessens in the collieries lying to the east until at Durie it is only about 120 feet.

From the foregoing account it will be evident that while most of the coal-field has been exhausted in those parts which have been long worked, there is probably still a large tract of coal to be won in the deeper portion of the field that lies towards the sea, north-east of Dysart. All the coals, or at least the horizons they occupy, run under the Firth of Forth, on the southern side of which they reappear in the Midlothian Coal-field. Already they have been followed under the sea. At West Wemyss the workings in the Parrot Coal have been pushed more than half a mile from the shore. "The Chemiss Coal," to quote from a statement supplied by Mr. Kirkby, "is at present being worked beneath and beyond tide-marks at the Rosie, Denbeath, and Leven Collieries. At the two former, I understand, it is fairly good coal; but at the latter nearly all the dip workings are (and have been for years) in very foul stuff—bits of stone where the coal should be, then a patch of coal, perhaps full height, perhaps not, time after time: just as though a very flat hitch, or a reverse fault, or a thrust on a large scale had continued in the coal over a large area. And at the Durie Colliery, further to the east, the same coal is found rising to the east (instead of dipping), and so foul that it has never been worked."

CHAPTER XV.

The Coal-bearing Group of the Coal-measures—continued.

ii. THE KINGLASSIE COAL-FIELD.

THE structure of this field has long been difficult to understand. The coals in it did not seem to fall into any recognisable association with those of any other part of Fife, though, as the Carboniferous Limestone series lies immediately to the north, they were at one time supposed to belong to that division of the Carboniferous system. There can be no doubt, however, that they must be classed in the true Coal-measures. In recent years the extent to which the district has been explored by boring has thrown fresh light on its geological structure, and Mr. James Grant Wilson, of the Geological Survey, has availed himself of this fresh information to delineate the area as it is now represented in the last edition of the Geological Survey Map (Sheet 40).

It will be seen from that map that the great fault which, coming up from the Clackmannan Coal-field, runs across Fife and brings the Carboniferous against the Old Red Sandstone rocks, either by itself or by a subsidiary branch enters the Carboniferous region to the south-east of Loch Leven and makes its way across to the sea north of Leven. This great dislocation forms the northern boundary of the Kinglassie field. As it proceeds eastwards it almost cuts out the whole of the Coal-measures, so as to reach the Millstone Grit. But a narrow strip of the upper series succeeds in escaping westward by Inchdairnie and expands eventually into a basin about 2½ miles long by a mile and half broad. It is this basin which makes the Kinglassie field.

Until a few years ago coal-mining had not been carried on with much energy, and for a while the only pit in operation ceased to be used. Since that time the ground has been largely explored and has been opened up to a considerable extent. The coal-seams of the Dysart field have been found in it, though with such variations in thickness and character and such differences in the nature and depth of the intervening strata that identifications of the individual seams with those of Dysart are perhaps somewhat doubtful. In particular the sedimentary strata between the separate coals appear to be much thinner than in the main coal-field. The following succession has been ascertained to exist:—

	Feet.	Inches.
Strata		
Coal ...	3	–
Strata ...	100	–
Coal ...	5	5
Strata ...	170	–
Coal ...	4	9
Strata ...	18	
Coal ...	5	
Strata ...	18	–
Coal ...	2	8
Strata ...	54	
Coal ...	4	4
Strata ...	120	–
Coal ...	4	9
Strata ...	30	–
Coal ...	3	9
Strata ...	15	
Black-band Ironstone ...	1	8
Coal ...	2	2
Strata ...	150	
Coal ...	4	
Strata ...	90	
Coal ...	3	

These coals are disposed in a synclinal trough which is truncated on the north by the great fault. Its western lip begins about 500 yards to the west of the farm of Kinninmonth, whence it strikes from the fault-boundary in a south-westerly direction to near North Bogside, when it turns round under Boglochty and bends northwards on the west side of Whinnyhall. There may possibly be another smaller basin of coal in the same field, somewhere to the south of Kinglassie. But the mineral capabilities of the ground can only be determined by boring exploration. The high stratigraphical position of the Coal-measures of this field is shown by the occurrence of some of the red strata of the upper group, to which further reference will be made on a later page.

II. Upper or Barren Red Sandstone Group.

Throughout the central region of Scotland, wherever the highest portion of the coal-bearing division of the Coal-measures is met with, it is found to be covered with another group of strata, evidently Carboniferous, for it contains the characteristic plants of the system. In the south-western or Ayrshire district this higher group appears to rest unconformably on the other Carboniferous formations. But in Fife no such break has been traced. The group of red strata follows on with apparently unbroken continuity upon the top of the coal-bearing group, there being a perfect passage of the one into the other. Again, in regard to this further portion of the Carboniferous system, the coast-section of Fife stands conspicuous above the other exposures of the same part of the system in Scotland. For a distance of four miles along the shore from Wemyss Castle to Leven the strata are displayed with hardly a gap in the series, so that their minutest details from the bottom up to the highest accessible members can be fully seen and studied.

It is well that so admirable a section should have been laid open, for the group can be examined nowhere else in the whole district. The map will show what a narrow strip is occupied by these red measures. Had there been no faults the outcrop of these highest Carboniferous strata might possibly have been laid open by the streams, as has happened inland to the other divisions of the system. But the effect of the dislocations is to shift the outcrop seaward by successive steps, and thus to prevent the strata from ever getting more than about half a mile from the coast-line.

The only inland locality where this group has been detected has been already alluded to in connection with the Kinglassie field, in which a small basin of the red sandstones and shales has been preserved. But even there only one trifling exposure of it has been detected by Mr. Grant Wilson in a water-course.

The strata that compose this group consist of red, purple, grey, yellow, white, and variegated sandstones, shales, clays, and marls, with some thin limestones and poor coals. The bottom, passing down into the lower group, crops out on the beach a few yards to the east of the *Lingula*-shale. The lower red sandstones, full of false-bedding and in places coarse and gritty, with quartz-pebbles, extend for nearly two miles along the beach, the trend of which nearly coincides with their strike. Beyond the Wemyss and Buckhaven Gasworks a thick mass of red, purple, yellow, white, and variegated clays comes in, followed by the red and purple sandstone of Buckhaven Harbour. Along the beach in front of the village, another zone of similar clays and shales alternating with sandstones is exposed. In its upper part it includes two seams of ochre, which was formerly worked and shipped. These strata are generally unfossiliferous, but Mr. Kirkby obtained remains of *Calamites* from one of the shales. Beyond their outcrop further sandstones, one of them a calcareous band, make their appearance, and are eventually succeeded by two thin coals underlying red sandstones. At this point the continuity of the section is broken by the large fault already referred to as striking from Earl's Seat to the coast at Broadhills Rocks. Several other faults cross the beach to the north of Buckhaven Links, and the two thin coals can be traced between them, the outcrops of these seams being successively shifted seawards. At last, about 560 yards to the south-west of Methil Harbour, the last fault is crossed and the regularity of the section is resumed. The two coals, of which the lower is three to six inches thick, and the upper from one to two inches, can now be traced obliquely across the beach to high water-mark nearly as far as the begining of the village. This platform is the most interesting in the group, so far as regards fossils. While the whole succession of strata is for the most part barren in organic remains, the series of shales among which these coals lie, and which may have a total thickness of about 70 feet, have been found by Mr. Kirkby to contain a number of vegetable and animal organisms. Among the shales lie some thin bands of impure limestone and a seam of reddle (keel) or hæmatite.

Each of the impure coarse coal-seams rests on a fireclay full of rootlets, and the upper seam passes seawards into black-band ironstone eight inches thick, with abundant valves of *Leaia* and other entomostraca. The upper coal has a shale roof, from which Mr. Kirkby obtained a considerable number of fossils, including several fishes (*Sphenacanthus*, *Diplodus*, *Ctenodus*, *Megalichthys*, *Strepsodus*), crustaceans (*Bellinurus*, *Eurypterus*, *Prestwichia*, *Leaia*, *Carbonia*), molluscs represented by *Anthracomya*, and a number of plants (*Calamites Suckowii*, *Calamocladus equisetiformis*, *Cordaites*, sp.; *Lepidodendron*, sp.; *Sigillaria camptotænia*, *Trigonocarpus*, *Neuropteris rarinervis*, &c.*

In a recent communication received from Mr. Kirkby he remarks with reference to the circumstances in which he obtained this remarkable assemblage of fossils:—"It is unfortunate that the locality where these fossils were collected is virtually a lost one, for the beds are now covered many feet deep with the spoil excavated from the new dock at Methil, and standage sidings for coals laid upon the new land thus made. The same strata are again seen near the Broadhill Rocks, on the west side of the Buckhaven Links fault, but less developed, and much less fossilferous."

Where the lower of the two seams of coal passes into black-band ironstone it contains a number of entomostraca (*Leaia Leidyi*, *Carbonia*, several species), also *Spirorbis pusillus* (*carbonarius*), fish-remains, and stigmarian rootlets. The band of reddle is composed of the entomostracan *Carbonia rankiniana*, together with occasional scales and spines of fishes. Below it lies a dark shale full of fish-remains.

Above this fossiliferous platform comes another succession of red, pink, purple, and greenish clays and shales, sometimes enclosing remains of *Neuropteris* and other plants, and alternating with sandstones, which increase in proportion higher in the section until they form almost the whole of the strata. The actual top of the group is nowhere seen, having been removed by denudation. The total visible thickness of the group cannot be much less than 1000 feet.

On the shore at Lundin Links the uppermost group of the Carboniferous system is pierced by a volcanic neck, which proves that eruptions took place after the Coal-measure period (p. 165).

In the Kinglassie field, the section, only some 200 yards in length, which has been exposed in a small outlier of this group between Kinninmonth and Redwalls, has been found by Mr. Grant Wilson to expose red sandstones, red and variegated clays, and thin limestone. The strata are said to include also a seam of blind coal.

* See Mr. Kirkby's paper, from which these details are taken. The full list is given in the Appendix to the present volume (p. 250).

CHAPTER XVI.

Intrusive Igneous Rocks in the Carboniferous System.

In the account of the Lower Old Red Sandstone given in the early part of this volume, the intrusive rocks, obviously forming part of the volcanic history of that region, were referred to in connection with the pile of andesitic lavas, tuffs, and volcanic conglomerates which constitute so vast a proportion of this division of the geological record in the Ochil Hills. Likewise in the description of the Carboniferous volcanic district of Burntisland, the various intrusive sheets and bosses of that part of the district were considered, together with the undoubtedly volcanic rocks to the age of which they may reasonably be referred. But there occur throughout the Carboniferous area of Central and Western Fife numerous intrusive rocks the geological date of which cannot be fixed further than that they must be younger than the strata into which they have been injected. To these rocks frequent allusion has had to be made in the preceding pages, but a more special and detailed account of them must now be given. Though almost entirely confined to the Carboniferous region, they are not entirely so, for, as has been pointed out, the Old Red Sandstone tract is traversed by a series of long dolerite dykes. But these must almost certainly be much later than the great mass of eruptive material that has invaded the Carboniferous formations. They will be considered by themselves as probably referable to the Tertiary system of dykes so abundantly developed in Scotland.

We have seen that in the Carboniferous strata of Fife two distinct series of igneous rocks occur, of which one was erupted contemporaneously with the sedimentary strata among which its members are intercalated, while the other has been intruded subsequently to the deposition of these strata. Throughout the foregoing chapters the former series has been taken together with its including and associated strata, so that a continuous record might be presented of the successive volcanic episodes in the geological history of this region. If these episodes be now arranged in stratigraphical sequence, it will be found that they group themselves into the following volcanic periods:—

Coal-measures	No contemporaneous volcanic rocks.
Millstone Grit	Do. do. do.
Carboniferous Limestone Series—	
c. Upper Limestone group ...	Tuffs of East Grange, Saline Hills, Cowden Wood, Lochore House, Aithernie Den (pp. 128, 133, 136, 141).

b. Workable Coal group ...	No contemporaneous volcanic rocks in Central and Western Fife.
a. Lower Limestone group ...	Lavas and tuffs of Seafield, which are a continuation of those in the Burdie House Limestone group below (p. 74).
Calciferous Sandstone Series—	
b. Burdie House Limestone group	Almost entirely volcanic in the Burntisland district, not elsewhere in this region (pp. 53-86).
a. Cement-stone group ...	Volcanic tuffs of Cult Hill and Georgetown Burn, a prolongation and dying out eastward of the great plateau - lavas and tuffs of the Campsie Hills (p. 41).

The eruptions in the Cement-stone group belonged to a volcanic centre lying among the Campsie Hills, far to the west of our region. Those in the Burdie House Limestone group began not long after that limestone was deposited at Burntisland, and continued with great vigour there until after the earlier of the marine limestones of the Carboniferous Limestone series were laid down. They discharged more lava than tuff, and continued intermittently active until they had piled up a succession of volcanic sheets to a depth of from 1500 to 2000 feet. There was then a protracted pause. In the long stretch of coal-field from Kirkcaldy westwards by Cardenden, Lochgelly, Loch Fitty, Kelty, Dunfermline, and Torryburn there is no evidence of any interruption of the coal-growths by volcanic action, though indications of such interruption appear to exist in Eastern Fife. But once more during the time of the Upper Limestone group the subterranean forces broke forth, though with rather less intensity. This time they discharged far more tuff than lava. They piled up the thick tuffs around the Saline Hills and the thinner prolongations towards the east. After these later eruptions, which seem to have ceased before the time of the uppermost or Levenseat Limestone, volcanic activity appears to have remained quiescent during the rest of the Carboniferous period.

In the present chapter we shall consider those igneous rocks in the Carboniferous system of Central and Western Fife regarding the age of which it is impossible to attain certainty. They are intrusive, and therefore necessarily younger than the rocks which they traverse. They embrace two distinct types that differ from each other greatly in structure, and probably also in age. One of these types is that of the Volcanic Necks, and the other that of the Sills, Bosses, and Dykes.

i. VOLCANIC NECKS.

Under this term are comprised the orifices from which volcanic discharges have taken place, and which are now filled up with some variety of rock, almost always of volcanic nature. The county of Fife is one of the best districts in the British Isles for the study of this variety of geological structure, inasmuch as the number of

necks there preserved probably exceeds a hundred. Some examples have already been referred to in Chapter VII. in connection with the volcanic history of the Burntisland district, but a more systematic account of this type of geological structure has been reserved for the present chapter, more especially with reference to the evidence which it furnishes of a volcanic series later than the Carboniferous period.

The general type will be understood if the necks are conceived as having been originally funnels, pipes, or chimneys which have been blown out of the earth's crust by volcanic explosions. In ground-plan they are circular, elliptical, or irregular. Not infrequently they coalesce as if two vents had adjoined, or as if a vent had slightly shifted its position. They vary in size from a diameter of only a few yards up to half a mile or more.

In accordance with the material which has solidified in the funnels the necks may be arranged in the following groups :—

1. Those in which the vent has been filled in chiefly, or entirely, with non-volcanic material.
2. Those in which the vent has been filled entirely with tuff or agglomerate.
3. Those in which molten lava rising in the chimney has penetrated the tuff or agglomerate in dykes, or as a plug.
4. Those in which the fragmental material, if it ever filled the vent, has been blown out and a column of basalt or other lava has solidified in the pipe.

Examples of each of these four types may be found in the county of Fife. In the first type, we have a spiracle or blow-hole made by the convulsive discharge of volcanic vapours, without the expulsion of ashes and stones, or at least with so little as to be hardly appreciable. The interesting vent at East Grange described on p. 137 is a good illustration.

The second type is exhibited in most of the smaller necks, and even in some of large size. As examples may be cited the small vents at Berrylaw, Cowdenend, Kingswood Cottage, near Burntisland, and Kennoway Den.

The third type includes the more important vents of the district, and indicates a more energetic exhibition of volcanic activity, when not merely ashes and stones were ejected, but when lava rose and eventually solidified in fissures of the fragmentary material within the funnel. The most perfect illustration of this structure is presented by the Binn of Burntisland, which has been described in Chapter VII. Other examples are the Saline Hills (Fig. 26), Hill of Beath, and Longside Hill, to the north-west of Kennoway, where the basalt shows beautiful columnar structure. Another example is probably supplied by the mass of tuff which has been discovered in the course of some boring operations at Letham, nearly two miles to the north-east of Kennoway. The mass, more than 3000 feet broad, as shown on the map, contains what appears to be the true neck of a vent, for while it is surrounded with sandstones which

crop out at the surface, a bore was put down inside the volcanic boundary to a depth of nearly 300 feet, and passed only through tuff. Abundant pieces of basalt gathered from the surface point to the existence of one or more plugs or dykes of material in the vent. This ground was examined and mapped by Mr. J. S. Grant Wilson, who examined the cores of the borings, and has supplied the information here given.

The fourth type is the least easy of all to discriminate satisfactorily, for a difficulty must obviously arise in distinguishing between a boss which never communicated with the surface and one which was actually formed by the solidification of molten material within a volcanic pipe. Indeed, unless some remains of the fragmentary discharges have been left, either along the walls of the chimney or around it outside, there may be no possibility of satisfactorily determining whether or not a given mass of basalt marks a true volcanic orifice, or has been injected independent of any superficial volcanic manifestation. A number of isolated basalt bosses in Central and Western Fife may thus be necks, though this origin for them cannot be proved. Probably some of the basalt eminences that rise amid the tuffs around Dunearn do really indicate the position of orifices connected with the eruptions of the Burntisland volcanic area.

While in the account given in Chapters VI. and VII. of the interstratified or contemporaneous volcanic rocks of the Burdie House Limestone group, it was convenient to take notice of the probable vents from which these rocks were discharged, a place must now be found for a number of necks about the age of which no such presumptive evidence of the period of the eruptions is to be obtained. They have risen through the Carboniferous system, and all that can be affirmed about their date is that they must obviously in each case be later than the particular subdivisions of that system in which they are found. Even when they rise at some distance from any of the Carboniferous lavas or tuffs, they may in some cases be associated with more or less confidence with these volcanic zones. Those which pierce the coal-bearing strata of the Dunfermline Coal-field, for example, cannot be so old as the Burntisland lavas and tuffs, but not improbably may belong to the volcanic eruptions of the Upper Limestones. On the other hand, there is no absolute proof that they may not be of a much younger date.

That volcanic action in this region did not finally cease with the eruption of the tuffs intercalated among the higher limestones is made quite certain by some of the necks now to be considered. But no interstratified lava or tuff has yet been detected above these limestones in any part of the Carboniferous system of Central and Western Fife. So far as the Carboniferous record of volcanic activity goes, it must in the meantime be regarded as having been definitely closed before the end of the Carboniferous Limestone period.

But there are some vents that mark the renewal of the eruptions

at one or more periods long subsequent.* One of these was detected by Mr. James Bennie and mapped by Mr. Grant Wilson. It rises through the Millstone Grit near Kennoway, where, as already mentioned, the coarse pebbly sandstones of that subdivision are well seen in the ravine called Kennoway Den, dipping towards S.S.E. (p. 144). At the south end of the village, below the school, they are pierced by a neck of dull green agglomerate. The relations of this mass to the surrounding strata are only partially visible, but the neck must be at least 100 yards in diameter. Among its component lava-fragments, pieces of finely vesicular basic pumice may be detected. It has enclosed some large masses of black shale and thin coal, one of which may be traced for several yards as a continuous layer in the volcanic rock. These portions of the neighbouring sedimentary rocks may possibly have fallen in from a higher part of the vent. The sandstones on the south side have been much disturbed. It may be added that among the fragments imbedded in this agglomerate, carbonised coniferous wood has been detected. Such fragments are of frequent occurrence in the volcanic vents of Fife and the Lothians.

Still more striking is the evidence supplied on the shore at Lundin Links (Sheet 41). Immediately to the west of the village the very highest portion of the Coal-measures of Fife, that is the red and purple sandstones and shales of the Methil shore, described on p. 159, are pierced by a volcanic neck which is well exposed on the beach. It is approximately circular in form, and has a diameter of about 170 yards. Round this vent, as may usually be observed when such good sections of the margin are accessible, the strata are much broken and indurated, and have been made to dip sharply into the sides of the neck, though their general inclination is eastwards at 10°–15°. The material of the vent consists in large measure of the debris of the surrounding and underlying red sandstones, clays, and shales. These materials are specially abundant towards the walls of the vent, and may indicate the first gaseous explosions by which the volcanic chimney was drilled to the surface. The later discharges, when lava had risen some way up in the pipe and had been blown into dust and lapilli, may be represented by the pale green fine-grained tuff which fills up the centre, and is full of fragments of altered shales and sandstones. Some of the latter have been indurated into quartzite. Through these various fragmentary materials veins of a compact flinty basalt have risen, which pass into a black basalt-glass. These veins, however, have not been confined to the neck, but may be seen traversing the strata around it, and indurating them. The shales have been hardened into a porcellanite, and the sandstones into quartzite.

This neck lies properly in the eastern division of Fife, and will be more specially referred to in the Memoir on that part of the

* A neck of tuff is said to have been encountered in digging the foundations for the gasometer at Kirkcaldy. This position is among the lower coals above the Hosie Limestones.

county. It is cited here on account of the importance of its evidence in regard to the volcanic history not only of Fife, but of Central Scotland as a whole. The great value of its testimony will be at once recognised from the fact that it has been blown through the very uppermost part of the upper division or barren red group of the Coal-measures. It demonstrates that volcanic action was manifested here at some time later, and possibly much later, than that in which these Coal-measure strata were deposited. Neither in this instance nor in that of the little vent at Kennoway have any tuffs or lavas survived that were discharged over the surface, so that no evidence remains that will serve to fix the date of the eruptions. But if one of the necks can thus be proved to be later than Coal-measure time it is obviously quite possible that some of the others which stand equally detached may belong to the same period, even though they only pierce the Carboniferous Limestone series. A large number of vents is scattered all over the east of Fife from Largo to St. Andrews, drilled through the Calciferous Sandstone and the Carboniferous Limestone series. These do not come into the district described in this volume, and, as they will be fully described in the Memoir of Eastern Fife, further reference to them need not be inserted here. They form a remarkably interesting assemblage, and though their geological age cannot be absolutely determined, plausible arguments may be assigned for regarding at least some of them as not improbably belonging to the Permian volcanic period, when so much subterranean activity was manifested in the south-west of Scotland.*

ii. SILLS AND BOSSES.

By far the largest proportion of intrusive igneous rocks in the Carboniferous region of Fife consists of sills and bosses of dolerite and basalt.

A Sill, as already explained, is a mass of molten material which has been injected between the bedding-planes of strata, and has solidified there as a bed or sheet. A Boss is the top of a column or irregular mass of igneous material which descends from the surface into the interior of the earth's crust. Where an intrusive mass has accumulated above the platform on which it rests so as to form a dome, and sometimes to ridge up the superincumbent strata as an overlying mantle, it is known as a Laccolite. When denudation removes the mantle but does not reveal the underlying platform, it is not possible to discriminate between a laccolite and a boss. Many bosses, if we could see beneath them, might be found to possess a laccolitic structure. It is often difficult also, or impossible, to distinguish bosses from sills where only surface indications are available. A sill may often be such a short thick (laccolitic) cake, or may be so reduced at the surface, that it looks like a true boss Though the two types may be differentiated in theory, they may obviously pass into each other; and every sill must

* See *Ancient Volcanoes of Britain*, Vol. II., Chap. XXXI.

have been connected with some boss or dyke that supplied its material.

Sills vary indefinitely in thickness and extent. Examples will be found in the present region of this wide diversity. Thus, from the limestone quarry of Dodhead, near Burntisland, a sill has already been cited (p. 84 and Fig. 16) only a few inches thick, which has been thrust so regularly along the stratification of the shales that it might at first sight be mistaken for a seam of sandstone. From this minute scale we may trace the same phenomena in every degree of magnitude up to sheets that must be several hundred feet thick, and, like those of the Lomond Hills, may extend over many square miles.

Sills are sometimes so regularly intercalated that their really intrusive origin might not at first be apparent to the casual observer. Such interstratified sheets are not unfamiliar to the miners among the coal-fields of Fife, who know them by the name of "whin-floats" or "floating whin." An attentive examination of them will often enable the observer to detect evidence of their true intrusive nature. In the first place, he will notice that the strata in contact with them are generally more or less hardened and even baked. Shales have been converted into a flinty jasper-like substance, while sandstones have been changed into quartzite. Still more marked is the alteration superinduced upon carbonaceous strata, more particularly upon seams of coal. These may be found in the state of "blind coal" or anthracite, or burnt into a mere cinder or soot. The distance to which the effects reach seems to vary within wide limits and under conditions not yet well understood. Much would obviously depend upon the size of the mass of invading lava. A thick sheet would no doubt alter the strata more and to a greater distance than a thin sheet. But there may have been circumstances connected with the temperature, percentage of dissolved water-vapour, and other conditions of the intruded material that had a powerful influence on the nature and extent of the metamorphism.

Reference has already been made to the remarkable alteration induced in basic igneous rocks, such as basalt, when they have come in contact with coal or carbonaceous shale. They then lose their dark colour and compact texture, and pass into a kind of pale clay known as "white trap." Yet even in the bleached, hydrated, and carbonated material, the decayed felspars may be recognised still in their original positions. Another change undergone by intrusive igneous rocks has been caused by their rapid cooling next the chill rocks with which they have come in contact. They present there a close-grained or chilled edge which is thoroughly characteristic and quite different from the rugged slaggy top and bottom of a lava poured out at the surface.

Again, the intrusive character of the sills may often be detected by their cutting through the strata among which they have been injected. In the case of the little sill at the Dodhead

Quarry (Fig. 16), it may be seen to form part of a vein which has risen from below and has then spread out between the layers of shale. Other examples of this structure have been cited in previous pages (see Figs. 15, 17, 20, 23, 24, and 25), and innumerable further illustrations might be gathered from all parts of Fife. Even where no actual sections can be seen that show the transgression of the igneous material across the bedding of the stratified rock, we can often be quite certain of such transgression by observing that a sill varies its horizon, either rising or descending so as to cut across strata, and then to run on upon a higher or lower platform than before (see Figs. 15 17, and 25). Good examples of this habit are to be met with in the great sills of the Lomond Hills.

It is obvious that sills do not in themselves supply evidence of the geological epoch of their intrusion. If our knowledge of igneous rocks were so minute as to enable us to decide their age by special characters of structure or composition, we might be able to use these characters, as we do fossils, to determine the dates of successive igneous protrusions. But no such convenient and generally applicable method of chronological classification has yet been discovered. All that in the meantime can be asserted in regard to the geological date of intrusive igneous rocks is that they must be later than the rocks through which they have risen. There may be grounds from other evidence, such, for instance, as the petrographical characters of an associated volcanic series the age of which is known, to assign some more or less definite geological date to intrusive masses, but in the present state of science this can hardly be done merely from the evidence furnished by the intrusive rocks themselves. We shall return to this question in connection with a consideration of the various platforms on which the Fife sills have been intruded.

The sills in the region with which this volume deals consist either of somewhat coarsely crystalline dolerite ("greenstone") or of some form of basalt. Their general petrographical characters have already been described (p. 81). As they appear at the surface, they usually form hummocky eminences on which the naked brown decomposing rock protrudes, and which are separated by grassy slopes and hollows. At their edges, where the strata underneath them come to the surface, they not infrequently form escarpments or lines of cliff. The great rocky scarps of the Lomond and Benarty sills are the finest examples of this structure in the district. But many others on a smaller scale might be cited from the ground to the north-west of Kirkcaldy, from Auchterderran, and from the Cleish Hills.

On examination of the map (Sheet 40) it will be found that the sills are distributed in two belts or bands which run parallel with each other in a general north-easterly direction. The more southerly of these bands belongs to the Burntisland district, and has already been considered in Chapter VII., together with the volcanic rocks of that part of Fife. The other or northerly

tract is of much greater extent and importance. What is seen of it in Central and Western Fife is only a part of a far larger band of sills, for it stretches to near St. Andrews on the one side and into the Clackmannan coal-field on the other. Far beyond the limits of that coal-field it reappears at Stirling and sweeps westward by the southern side of the Campsie Hills. In a more broken line it can be traced beyond Glasgow into Renfrewshire.

Throughout this strip of country for a length of nearly 80 miles hundreds of sills have been injected into the Carboniferous formations, more particularly about the base of the Carboniferous Limestone series. The broadest part of the belt lies in Fife, and there perhaps the phenomena of sills can be most fully studied. The thickest and broadest development of the intruded material is to be seen in the area of the Lomond Hills. Two sills have there been thrust between the strata near the base of the Carboniferous Limestone series. Each of them varies in thickness, but their average dimensions may range between 250 and 300 feet. Owing to extensive

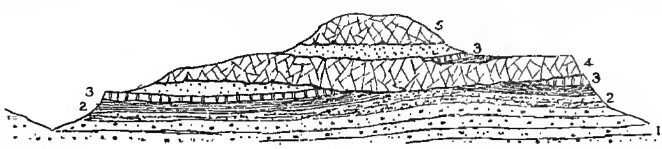


Fig. 29.—Section across the West Lomond Hill to show the intrusive nature of the Dolerite Sills.

1. Upper Old Red Sandstone. 2. Calciferous Sandstone series. 3. Hurlet Limestone. 4. Lower sill. 5. Upper sill.

denudation, the upper sheet has been much reduced and now forms the capping which crowns the summits of the East and West Lomonds. The lower sill covers a larger area and has protected the limestone and shale below it, which crop out from under its escarpment. In following that escarpment we may convince ourselves that although the igneous rock looks at first as if it were regularly bedded with the strata among which it lies, it nevertheless gradually passes from one stratigraphical platform to another (Fig. 29). Thus, on the northern front of the West Lomond, its base gradually descends, cutting out successively the black shales and sandstones between the Hurlet Limestone and a higher limestone seam, then the Hurlet Limestone itself, and then a part of the shales underneath that seam. It then gradually ascends again until it regains its previous horizon. On the Bishop Hill it somewhat undulates in its stratigraphical level, but towards the south end of the ridge it quickly cuts out the strata overlying the limestone and then still more quickly mounts to a higher platform above a limestone that overlies the Hurlet seam. The great Benarty sill, which lies about three miles to the south-west, is probably a continuation of the Lomond sheet, but it descends to a still lower platform, for it has invaded the Calciferous Sandstones near their bottom and actually crosses the basement cornstone so as at last to lie upon the Upper Old Red Sandstone.

It is seldom possible to detect the dyke or pipe up which the material of the sills rose. Not improbably some of the isolated bosses that lie around the sills may mark the sites of such channels of supply. There is no system of dykes in connection with the sills, so that it may be inferred that they were injected from orifices or chimneys like those of the necks, rather than from fissures. Still there may be dykes as well as neck-like columns of dolerite or basalt concealed underneath the sills themselves.

The extravasation of such an enormous volume of molten material is one of the most striking as well as one of the most difficult problems in Scottish geology. The vertical thickness of the successive sills on different horizons, if they could be placed one above another, would amount to several thousand feet. In the Lomonds alone the two sills make a combined mass some 500 or 600 feet thick. It is difficult to realise the mechanical process by which such prodigious quantities of molten rock were thrust between the planes of the strata over such wide areas, and under the pressure of so thick an overlying mass of the terrestrial crust. Was this process part of a volcanic episode? If so, were any lavas and tuffs then emitted? No evidence has yet been forthcoming satisfactorily to connect the great belts of sills with any volcanic action in the geological history of the country. Then arises the question as to the time when the sills were injected. Do they all belong to one period or were there successive epochs of intrusion?

In considering the question of the date of the sills we have first to take note of the stratigraphical position of the formations into which they have been introduced. It will be noticed that none appear in the Old Red Sandstone, with the exception of the end of the Benarty mass above referred to. Yet we know that every one of them must be connected with a channel of communication, which in providing a passage for their material, necessarily came through the Old Red Sandstone as well as all other rocks of the district which underlie the Carboniferous formations. As above mentioned, the sills are most numerous and thickest in the lower part of the Carboniferous Limestone series, which seems to have been a favourable horizon for them all the way from St. Andrews to the hills of Renfrewshire. But they are not equally developed in all the districts where that portion of the Carboniferous system is displayed. Though not confined to the northern belt they are chiefly displayed there, while the same formations a few miles to the south are almost free of them.

If, however, we examine that northern belt a little more attentively we shall find that the sills are far from being confined within any narrow stratigraphical limits in the Carboniferous system. They invade every group of strata successively from the very base of the Calciferous Sandstones up to the top of the Upper Limestone group. Not only so, but they ascend into the higher subdivisions of the system. At Auchterderran and Markinch they come through the Millstone Grit. The Coal-measures in the Dysart field are singularly free from them. This area, indeed, is

the largest extent of Carboniferous strata in Fife which has escaped invasion by intrusive sheets of dolerite or basalt. Had no other evidence been forthcoming an inference might have been drawn from the negative testimony of the Dysart field that the injection of the sills took place prior to the Coal-measure period. But that such an inference would have been fallacious is clearly shown by that portion of the Coal-measures which lies to the west of the anticline and expands into the Kinglassie coal-field. There the strata come within the belt of sills and have been pierced by the eruptive material of which at least half a dozen different intrusions have been observed.

There is, of course, no proof that all the sills belong to one period of injection. Those in the Burntisland district and to the north-west of Kirkcaldy may not improbably have been connected with the volcanic phenomena of the time of the Calciferous Sandstones. Others may have formed part of the long and vigorous eruptions of the Carboniferous Limestone period. But having found no means of discriminating them, we must in the meantime leave the question of their age undetermined.

While there can be no doubt that some of them are later than the Coal-measures, it by no means follows that only those are so recent which actually pierce Coal-measure strata. It is possible that many others belong to the same late period. This problem, however, is too wide to be adequately discussed here. It involves a consideration of the whole evidence of the intrusive sheets of the Scottish Coal-measures, and of the proofs of volcanic activity in the country subsequent to the Carboniferous period.

With regard to the Bosses of the district, perhaps enough has already been said about them in connection with the necks and sills. Some of the eminences of igneous rock which look like bosses may, as has already been explained, be small or denuded sills. Thus the two conical knobs that form the summits of the East and West Lomond Hills, though they might be taken at a little distance for obvious bosses, are nevertheless only portions of sills which have been reduced by denudation to mere outliers (Fig. 29). Of the true bosses, some, as we have seen, may mark the sites of the funnels up which the material rose that formed the neighbouring sills. Such, possibly, is the history of a few of those in the districts of the Cleish Hills and of Kinglassie. Others, again, are more probably connected with volcanic action and may mark the positions of true vents, as above mentioned. Of these the Burntisland district perhaps supplies a few instances.

iii. DYKES.

In previous pages reference has been made to various dykes and veins of intrusive material which rise through the Carboniferous system. They are specially abundant in the necks of tuff. Admirable examples of them have been cited in Chapter VII. from the great precipices of the Binn of Burntisland. These, there can be little

doubt, belong to the vents themselves and form part of the volcanic history of each orifice. With the exception of such cases, and a few thin veins sometimes connected with sills in the Burntisland district (Fig. 18), there are hardly any dykes to be seen in the Carboniferous region of Central and Western Fife. The most important of them, that of St. David's, has already been described in connection with the volcanic rocks of the Burntisland district. But it differs so much from the other forms assumed by the igneous rocks around it that it may possibly belong to a much later series of dykes of which some account will now be given.

One of the most remarkable features in the geological structure of the southern half of Scotland is the number of parallel dykes of dolerite, basalt, or andesite, which run across the country in an east and west or south-east and north-west direction. These dykes are not all of precisely the same age, for some are found to intersect others. Such intersection is of course quite compatible with the idea that the the whole assemblage of them belongs to a single geological period, during which the uprise of molten material in fissures took place at various intervals. On the other hand, a long succession of geological periods may possibly have intervened between the production of the earliest and the latest dykes. Of the date of the earliest we know nothing definite, but that of the latest series can be more precisely fixed, for these dykes cross all the formations that lie in their way and traverse even the most gigantic faults without deviation. Beginning in the north of England, where they traverse the Jurassic rocks, they increase in development north-westward, and attain their greatest number among the Tertiary volcanic plateaux of the Inner Hebrides. It is now generally agreed that this system of dykes belongs to the history of these plateaux, and dates from older Tertiary time. At least four examples of dykes which may probably belong to this late series come into the region described in this volume. They will be seen to be confined to the area of the Ochil Hills, unless the St. David's Dyke, just referred to, be included among them.

The most southerly of the number may be traced along the southern slopes of the hills from Dochrie in an E.N.E. direction to Tilliery Hill at a height of 1080 feet. It is then lost for a little more than a mile, either because the igneous rock does not there rise to the surface, or because it is concealed under the drift deposits of the intervening valley. We catch it up again on the east side of Langside Plantation, and can follow it by the farm of Carmore, where it crosses into a bay of the Upper Old Red Sandstone. Holding still along the same straight line it runs for more than 11 miles into the hills beyond Auchtermuchty. But it stretches much further than the limits of the present map, for it extends to Balgarvie, near Cupar, and it is not improbably continued in the conspicuous dyke of Strathkinness and Kinkell, near St. Andrews—a total length of more than 30 miles.

The second example is much shorter and does not run quite in the same direction. It is exposed in quarries on either side of the

road south of Damhead, Glen Farg, and can be followed for five miles in a slightly sinuous line nearly due west to Auchtenny Wood. A few small dykes of dolerite, not impossibly connected with this member of the series, may be observed in the ground on either side of it. Such subsidiary dykes along the course of a main one are not infrequent in the Tertiary dyke-system.

The third dyke runs for a mile and a half through the tuffs and lavas of the hills on the north side of the Water of May above Path of Condie, and strikes a little south of west.

Two dykes cross the line of the Dunning road on the north and south sides of Cockersfauld. The more northerly of these is here much more persistent than its neighbour, for it has been followed for about seven miles from Barnhill on the Water of May to the Pairney Burn, south-east of Auchterarder, following a direction from a little north of east to a little south of west. On the same line of strike what is not improbably a continuation of the same dyke is well seen in a large quarry close to the Auchterarder Station of the Caledonian Railway. The central portion of this dyke, as there displayed, is a coarsely crystalline olivine-dolerite with sub-ophitic structure, but towards the margin the rock becomes much closer-grained, and finally passes into a selvage of black basalt-glass, which is 1·5 centimetre broad. Inside this selvage the rock is distinctly micro-crystalline, and rapidly assumes its ordinary coarsely granular texture.

The more southerly and apparently less important dyke of Cockersfauld cannot be so continuously traced for some distance to the west, but a little further in that direction (in Sheet 39) what may be the same dyke has been followed for a length of nearly two miles. It is not impossible, however, that though their prolongation has not been detected at the surface, one at least of these two dykes may have a much longer course, for some five or six miles beyond the point to which it has been mapped a similar dyke begins on the west side of the Tullibardine Wood and runs westward for at least nine miles.

Still more remarkable is the persistence of a third dyke which also crosses the Dunning Burn immediately above Pitincailow, but has not been detected further east. From this point, however, with occasional intervals of space where it is lost, it may be detected in many natural and artificial openings westward through the peat-covered hills above the Braes of Doune (Sheet 39), across Uam Var and the great Highland fault into the Highland schists to the north of Callander. It then turns south-westward among these ancient crystalline rocks, crosses the Pass of Leny, likewise Lochs Vennachar, Ard, and Lomond. Thereafter climbing the lofty ridge north of Luss, it descends into Loch Long, reappears on the further side of that fjord, traverses Glen Finart and Loch Eck, and only ceases to be recognisable among the hills of Cowal. Its total traceable length is thus between 60 and 70 miles.

CHAPTER XVII.

Faults.

THE more important faults and their effects on the geological structure of the region have been described in the previous pages, but some generalised account of the dislocations may be of service here.

At first it might seem as if no system could be made out of the faults; they appear to run in all directions. Yet a little attention will show that this confusion is more in appearance than in reality.

The first impression on the mind of anyone who looks over the map will probably be that the Carboniferous district has been far more dislocated than that of the Old Red Sandstone, and that of the whole Carboniferous fields those containing the workable coals have suffered far more than the rest. Yet such an impression would on further consideration be found to have no adequate foundation. The faults represented on the map are those which have been ascertained to exist. The great majority of them make no sign at the surface, but on the contrary are concealed under the widespread accumulation of superficial deposits by which the rocks below are so generally hidden from view. They have been detected in the underground workings of the coal-pits. If there had been any similar subterranean explorations in the Old Red Sandstone, we should doubtless have found that region just as much faulted as the coal-fields.

It is certainly noticeable that those portions of the coal-fields which have been equally well explored are not all dislocated to the same extent. The Kelty coal-field, for instance, has to a large extent escaped the fracturing which has befallen the neighbouring fields, though even there faults occur, and these include at least one case of a thrust or reversed fault. Again, the southern half of the Dysart field, though traversed by some large faults, has not been sliced into strips as the northern half has been, or as the group of lower coals between Cardenden and Carnock.

The great faults that have so largely determined the geological structure of Scotland have followed a general north-easterly trend, sometimes veering rather more to north and south, and sometimes more to east and west. The course of the two great lines of dislocation that have defined the limits of the Midland Valley are examples of this north-easterly strike. From Stonehaven to the Clyde the fault that separates the crystalline schists on the one side from the Old Red Sandstone on the other marks out at the same

time the boundary between Highlands and Lowlands. One of the dominant lines of dislocation which, by bringing two formations together, define the limits of two types of scenery, has been already described as crossing the breadth of Fife. (Sheets 39 and 40.) It begins in the neighbourhood of Stirling, and runs thence in a direction a little north of east along the base of the Ochil Hills. by Menstrie, Alva, Tillicoultry, and Dollar. Its effect there has been to depress the Coal-measures of the Clackmannan Coal-field against a low part of the Lower Old Red Sandstone. The extent of the displacement here amounts to nearly the total thickness of the Lower Old Red Sandstone and the Carboniferous system, and can hardly be set down as less than 10,000 feet. The striking influence of this fault on the scenery of the district is shown by the abrupt rise of the great wall of the Ochil chain above the Coal-measure plain in front.

This powerful fault continues in full force as far as Dollar, after which it rapidly lessens in the amonnt of its throw and appears to split into two branches. One of these turns off to the south-east and can be traced for some four miles into the ground south of Cult Hill (Sheet 40), which we have already dealt with. The effect of this branch dislocation is to bring down the Millstone Grit against the Upper Old Red Sandstone and Calciferous Sandstones. The other branch is more distinctly a continuation of the main line of fracture. It turns somewhat to the south-east, bringing down the Calciferous Sandstones against various subdivisions of the Upper and Lower Old Red Sandstone. Keeping eastwards by Cleish to the north end of the Kelty coal-field, it begins thereafter to return more to its original trend—a little north of east. Beyond Navity Hill, its further progress eastward for some miles has not been definitely ascertained. Not impossibly the fault may branch here, as has been suggested on p. 157. One branch may perhaps skirt the southern edge of the alluvial plain of the Leven River, and following the line of the valley may join the great dislocation which has been proved to exist to the south of Markinch and to run thence eastward to the sea. No actual proof, however, has been obtained of this route of the fault. On the other hand it can be shown that either the main dislocation or an important branch from it strikes eastward from the end of Navity Hill and passes along the north side of the Kinglassie coal-field. This fault can actually be seen near Kinninmonth. But its course to the east of the coal-field is not known, though a conjectural line has been put for it on the map to define the limits of the several subdivisions of the Carboniferous system in that part of Fife. There can be no doubt of the position and trend of the great fault which passes from Markinch to the sea near Leven, for these have been fixed by bores and pit-workings.

To this important boundary-fault frequent allusion has been required in previous chapters. About the western end of the Cleish Hills, it throws out a large part of the Calciferous Sandstones and all the Upper Old Red Sandstone—that is, it produces a dis-

placement of more than 2000 feet. Further east, on the flanks of Benarty Hill, it brings down some of the higher coals of the field against the Upper Old Red Sandstone, and must thus effect a shift amounting to the whole depth of strata from these coals to the very bottom of the Carboniferous system, that is, at least 3000 feet. A little further on, this throw is increased where a portion of the actual Coal-measures of the Kinglassie field is thrown against the fault. From this point to the sea, the line of fracture is no longer a boundary between distinct geological systems, but runs entirely between the various subdivisions of the Carboniferons series. At Markinch, as we have seen, the north end of the great anticlinal arch is broken through, and the Millstone Grit is faulted against the Calciferous Sandstones, which must mean a displacement there of more than 1500 feet. From that locality eastward, the amount of throw gradually diminishes until, where only a higher part of the Coal-measures is brought against a lower, the fault runs out to sea with a displacement of perhaps not more than 500 feet.

Next in magnitude to this great boundary-fault we should probably place the dislocation which runs in a similar E.N.E. direction from Loch Fitty into the Oakley coal-field. As we have seen, it limits the Dunfermline field on the north, inasmuch as it throws out the coal-bearing strata in that direction and brings them down against the Lower Limestones and Calciferous Sandstones. Its throw there cannot be less than 600 feet.

It will be observed from the map that the prevalent trend of the faults in the lower coal-bearing group from Kirkcaldy westward into the Oakley field is along W.N.W. lines, that is, rather oblique to the greater faults just referred to. Where they run against the latter they are arrested by them, as may be seen along the south side of the Loch Fitty fault.

In the Dysart field a general east and west direction will be noticed to have been taken by most of the larger faults. On the north side of the great boundary dislocation, which diverges across the coal-field to the sea, there are two large parallel faults, whereby the outcrops of the Carboniferons formations have been considerably shifted. The smaller faults follow more divergent lines. That which strikes the coast close to Buckhaven trends along an E.N.E. line, and has a throw which increases seaward to 600 feet. The anticlinal fault between Milltown and Dysart follows a nearly north and south line.

With regard to the direction of downthrow it may be observed that there is a predominant tendency towards the south. This is most distinctly seen in the Dysart field, where each of the long parallel east and west faults depresses the strata on its southern side. But the same predominance may be traced among the numerous W.N.W. faults from Cardenden to Oakley. These dislocations have undoubtedly broken up the coal-fields, damaged the coals, and complicated the underground workings. On the other hand, but for them a great deal of the coal would have been buried to a profound depth and would have needed deeper pits and

more costly pumping machinery. We have only to study the manner in which, by means of the faulting, the coals are again and again brought up towards the surface, to be enabled to realise that the dislocations have not been altogether without their economic value.

The faults now described are what are known as *normal* dislocations, that is, they "hade" or slope towards the side which has sunk down. They may have resulted from the mere subsidence of one side of a rent in the earth's crust, or one side may have been pushed up, or the two movements in opposite directions may both have occurred. They do not necessarily imply any serious horizontal or tangential thrust of one part of the crust over another. The Carboniferous rocks of Fife, however, present a number of cases where such a horizontal push has taken place, and where the hade, instead of being vertical as in most ordinary normal faults, is inclined at a low angle. Such thrust-planes or reversed faults indicate considerable lateral pressure within the crust. An instance of the structure has been already cited from the Kelty Coal-field (Fig. 21) and another from the Kirkcaldy pits (Fig. 25). But reference may be made to several examples which the observer can easily examine for himself. They occur among the Hosie Limestones on the shore south of the Tyrie Bleach

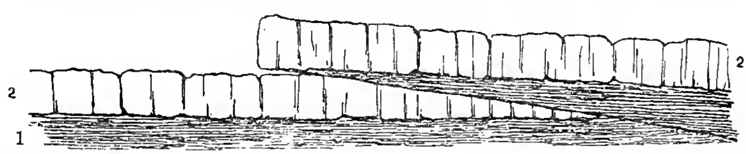


FIG. 30.—Section of Thrust-plane or Reversed Fault in one of the Hosie Limestones, Shore, south of Tyrie Bleach-works, Kirkcaldy.
1. Shale. 2. Limestone.

Works, near Kirkcaldy. In one of them, as represented in Fig. 30, a seam of limestone, between two and three feet thick, has been shoved horizontally over itself, so that the underlying shales come to lie above one part of the seam. A vertical shaft would here pierce the seam twice—which could never happen in the case of a normal fault. The undermost part of the limestone has been partially brecciated and striated or "slicken-sided" by the rubbing of the overlying mass upon it, and the movement appears to have been in a direction from E. 10° N. to W. 10° S.

The question of the age of the faults in the region raises many difficulties which at present cannot be solved. The dislocations not improbably belong to more than one period of earth-movement. The E.N.E. series, which includes the great boundary faults, is probably the oldest. The W.N.W. series is obviously later, and may possibly have resulted from one continuous succession of subterranean stresses. Probably most if not all of the faults are later than the sills. They can often be seen to have dislocated them, as is well shown at Capeldrae. Perhaps this relation would

be more frequently observed than it has been if there were more evidence on this subject available from the records of coal-mining. No essential difference can be perceived between the faults in the higher and those in the lower part of the Carboniferous system. We may legitimately infer that they are of later date than even the uppermcst Coal-measures.

CHAPTER XVIII.

The Glaciation and the Glacial Deposits.

CENTRAL and Western Fife have shared in all the changes of climate and geography which marked the passage of the Ice Age in the middle of Scotland. The region was entirely overflowed by the sheet of ice that descended from the mountains of the Highlands and left a characteristic impress everywhere on the solid rocks. When the ice melted away from the lowlands, the valleys, and at least the bases of the hills, remained buried under the boulder-clay and other deposits that were left behind. Towards the end of the time, the country lay 100 feet lower in level than it is to-day, and the memorials of the coast-line of that period are still distinct, while there remain also traces of some of the stages in the gradual elevation of the land into its present position. The records from which this interesting part of the geological history is compiled are to be found in the following sources of evidence. No strictly chronological order of these materials can be followed, seeing that several of them were partly contemporaneous; but the earliest are placed at the bottom of the list, while some of the youngest are ranged at the top:—

(6) Raised beaches and terraces of different ages.
(5) Ancient lakes.
(4) Sands and gravels—Kame or Esker series.
(3) Erratic blocks.
(2) Boulder-clay.
(1) Ice-worn rock-surfaces.

The boulder-clay, erratics, sands and gravels have been classed together under the general name of Glacial Drift. The rock-surfaces on which they rest are often found to be smoothed, polished, and striated, and present an impressive picture of the extent and erosive power of the ice. The seaward edges of the Drift have been cut into terraces by the sea, and the oldest of these terraces or raised beaches undoubtedly belong to the Ice Age.

(1) ICE-WORN ROCK-SURFACES.—Though the general contour of the ground still retains much of the rounded form imprinted on it by the grinding action of the ice-sheet which for many ages moved over it, the finer markings on the rock-surfaces have generally disappeared in exposed situations. But wherever the covering of superficial deposits has protected them, these markings may be found as fresh as at the time when they were originally engraved

by the sand and stones that were pressed along between the ice and the bottom over which it slid. A study of them reveals the magnitude of the ice-sheet, and shows the direction in which it moved across the district. They have been found high on the Ochil range, and their evidence, combined with that of the blocks of rock transported from the Highlands, shows that range of heights to have been entirely buried under a mass of ice which moved down from the mountains of Perthshire, over-rode the Ochils, and passed eastwards into what is now the basin of the North Sea. A few of the observed directions of the striæ on the rocks will here be given, from which the march of the ice has been determined.

Over the hilly ground to the south and east of Dunning, the ice has moved in a general E.S.E. direction. On the ice-worn surfaces of andesite at Glencarnhill, the direction is E. 25° S.; on Fordel Hill, half a mile west of Lustylaw, E. 29° S.; on the north slope of the Black Hill of Kippen, about a mile to the south-west of Dunning, E. 35° S.; at Craig Bakie, three miles south of Dunning, E. 35 S.; on Dochrie Hill, about three miles north-west of Milnathort, on a well ice-worn ridge, E. 45° S,; half a mile north-east from Heatherieleys, E. 40° S. On the hills to the north-west of Damhead the *roches moutonnées* are abundant and well preserved, the striæ pointing generally towards the S.E. The ice has moved along grooves probably worn by itself in the igneous rocks, and has sometimes striated even a vertical face of rock. Owing to the form of the ground the lower parts of the ice were sometimes embayed and made to follow directions not quite the same as the general movement. Thus while on Dochrie Hill, at a height of nearly 1000 feet, the top of the ridge has been scored towards E. 45° S., the striæ in the hollow to the west, a hundred feet lower, are pointing to S. 25° E. But as soon as the southward slope of the hills was reached, the bottom ice resumed the normal trend, so that a mile to the south-east the striæ near Craigowmeigle have become E. 30° S.

As the ice-sheet descended from the Ochil chain into the lower grounds of Fife and Kinross, it began to bend round more to the east, and eventually round to the north of east, as it approached the sea. There are traces of this change of direction even on the flanks of the Ochils. Thus close to Douranside, two miles north-west of Milnathort, the striæ point to E. 15° S. To the west of the district described in this volume, well-marked striæ have been preserved on the sandstones of the Coal-measures and Millstone Grit to the north of Kincardine-on-Forth pointing a few degrees south of east. The same direction continues eastward through the centre and south of Fife. Thus near Cattle Moss, $3\frac{1}{2}$ miles north of Culross, near the edge of Sheet 39 of the map, the striæ point to E. 5° S. But as the ice descended further from the hills and was able to spread out more upon the lower grounds, it engraved the striæ more towards the east and then towards the north of east. At Lochend Quarry, a mile north of Dunfermline, the markings left on the surface of one of the intrusive sheets point to E. 10° N.,

and on the coast to the west of Pettycur the basalts have been scored in a similar direction. Many miles to the east the same trend is displayed on the well ice-worn surface of a dolerite sheet which is quarried near Craigrothie, a little to the west of the village of Ceres.

(2) Boulder-clay.—This deposit has been left by the ice over almost the whole of the ground, from nearly the crest of the Ochil chain down to below sea-level. It varies in character according to the nature of the rocks of the district in which it lies. This variation is best seen in its colour, which depends upon the prevalent tint of the surrounding rocks. Thus, where derived from the Old Red Sandstone, the boulder-clay is red; in a Carboniferous district, where its materials have come from the carbonaceous shales, coals, and fireclays of the Carboniferous system, it is dark blue or nearly black. The texture and composition in like manner are determined by the materials out of which it has been formed. When these have moved from a region of sandstone it is of a loose sandy texture; where, on the other hand, the rocks have been largely argillaceous, it becomes a stiff clay.

Throughout the matrix of the deposit are irregularly scattered numerous pebbles, boulders, and large blocks of rock. These, when of a nature to receive and retain any markings engraved upon them, are found to be smoothed, polished, and striated in the same way as the solid rocks have been treated over which the ice-sheet moved. An examination of the stones in the boulder-clay shows that the great majority have been derived from the neighbouring region, while a small proportion has come from greater distances, sometimes 30 miles or more. By fixing the sources from which the boulders have come we are enabled to follow the direction in which the transport of material has been effected, and we find that this kind of evidence is in entire harmony with that of the striation of the solid rocks. The two kinds of proof furnish an impressive demonstration of the existence, mass, and movements of the great ice-sheet.

In the part of the Ochil chain which has been described in this volume the boulder-clay ascends to a height of at least 1250 feet above the sea. As it was there pushed along under the ice from a north-westerly direction it has especially accumulated on the lee-sides of the valleys. This is well seen in the traverse of the hills described at p. 18. On the west side of the Glendey Valley, which runs nearly north and south, the boulder-clay is at least 100 feet thick and runs far up the slope, while on the east side it is comparatively scant, and the naked rock appears in many places.

The magnitude of the boulder-clay as a superficial deposit is impressively displayed in these Ochil valleys. Its smoothed and rudely terraced surface can be traced by the eye up to the heads of the corries, where it is trenched by the descending streams. Raw scars of it, laid open at first by the rains and runnels, are often in the end grassed over and become steep verdant banks, while new scars are cut above or below them. Where the clay fills up the bottom of a valley, the stream may be seen to wind about between

a succession of these grassy slopes, with here and there a fresh face where the vegetable cover has been dislodged by landslips, and the boulder-clay is laid open to the air. In such places the channel of the water-course is often heaped with boulders that have fallen out of the clay during the gradual erosion of the valley.

In the lowlands the boulder-clay has frequently been laid down in ridges, or what are called "drums" or "drumlins," which correspond in general direction with the trend of the striæ on the rocks. Long ridges of the same material may be observed on the lee of the hills and crags, pointing away from the quarter from which the ice moved.

Although itself an unstratified deposit, the boulder-clay here and there includes layers of stratified sand, gravel, and clay. Conspicuous examples of this nature occur in the Glendey Valley just referred to. There are occasional indications of a difference in colour, texture, and contents between the lower and upper parts of the boulder-clay, pointing to variations in the direction of movement of the ice-sheet. As the deposit is traced upwards into the higher valleys of the Ochils it becomes loose and earthy, and then resembles the ordinary moraine-stuff of local glaciers.

Throughout the hilly tracts and the lowland south of the Howe of Fife, the boulder-clay occupies the lower ground, and creeps up the slopes of the hills, sometimes almost to their tops on the lee-side. Thus, on the Lomonds, while the north-west front, facing the direction from which the ice came, is nearly bare of boulder-clay above a height of 500 or 600 feet, the southern or lee side shows this deposit ascending to heights of more than 1000 feet. It has accumulated to a considerable depth in some parts of the Howe of Fife. Thus, on the steep slopes of the recess in the great line of escarpment, between the Cults Lime Works and the plain, it is more than 15 feet thick, as has been shown by the cutting made in it by the tramway from these lime-works. The boulder-clay spreads over the plains towards the sea, where it has been cut back by the waves at the time of the 100 and 50 feet raised beaches. Such ancient sea-carved cliffs of boulder-clay, masked under grassy vegetation or blown sand, may be seen at various points along the coast, between Torry and Queensferry, and between Dysart and Leven. But the deposit descends beneath sea-level, and lies deeply over the bed of the Firth of Forth. This extension may have considerable industrial importance in the future. As the coal seams are worked under the firth, the presence of a thick impervious clay above the Carboniferous strata will permit the mining operations to be carried on with little or no risk of any inrush of the sea from above.

(3) Erratic Blocks.—Under this name are classed the boulders which do not belong to the rocks on which they lie, but have come from a greater or less distance. There can be no doubt that a large proportion of them are relics of the boulder-clay. They serve to show how greatly this deposit has been wasted since it was laid down. Some of them, however, may have been carried on the

surface of the ice-sheet and have been dropped when the ice melted. They are strewn by thousands all over the region from the crests of the highest ridges down to below sea-level. As already mentioned, the testimony which they bear to the march of the ice-sheet completely harmonises with and corroborates that of the striæ on the solid rock. These boulders demonstrate that the transport of detritus has been from the Highlands in a south-easterly direction, and from the Ochils towards the east, and then to the north of east.

The most striking erratics are those which can be proved to have come from the greatest distance, and these include a large variety of boulders from the Southern Highlands. The gneisses, phyllites, schists, greywackes, pebbly grits, epidiorites, and other rocks of the mountains between Loch Katrine and the valley of the Tay are strewn in countless numbers over the Ochil chain far east along the estuary of the Tay and to the south upon the hills and plains down to the margin of the Firth of Forth. Some illustrative examples of these "foundlings" may here be given.

Perhaps the largest transported mass which has yet been observed in Fife is the limestone already referred to (p. 126) as having been worked in Kilmux Den. It was so large as to have been opened out for a lime-work, and was extensively quarried for years until it was exhausted, and found to have been only a large boulder lying on boulder-clay. It had been carried by the ice from some of the outcrops of limestone some miles to the westward.

On the slope of Boghall Hill, nearly two miles to the south-east of Dunning, a block which may have come from one of the basic sills in the mountains between Ben Chonzie and Aberfeldy is known as The Grey Mare. It measures upwards of 300 cubic feet, and has probably travelled at least 20 miles across the plain of Strathearn. In the valleys of Glendey and Glen Farg, which have been described at pp. 20, 25, the burns are sometimes choked up with Highland boulders. On the hills above the Devon, a mile to the north of the Yetts of Muckhart, many boulders of mica-schist, gneiss, and other crystalline rocks are strewn over the ground at a height of 1000 feet above the sea. Again, on Third Hill, five miles south of Dunning, among a group of Highland boulders lying at a height of 1200 feet a block of grit may be noticed which measures 36 cubic feet.

On the Cleish Hills, blocks from the Highlands are of common occurrence. Thus, on the north shores of Loch Glow, boulders from that region may be seen at a height of nearly 900 feet above the sea. These stones have been carried not only across Strathearn, but completely across the chain of the Ochil Hills and the plain of Kinross. They may be followed down even to the margin of the Firth. At Cairneyhill, 150 feet above the sea, lies a block of gneiss measuring 96 cubic feet, and the train of Highland erratics may be traced to the far eastern headland of Fife.

These stones are easily noticeable from the contrast they present

to the rocks of the district. They are hard and durable, and hence have survived their journey better than most of the younger rocks would have done. But we have also evidence of the transport of boulders from the Ochils towards the south-east and from the doleritic sills of the Cleish and Lomond Hills to the sea. About a mile to the south-west of the Dunfermline Compensation Reservoir a boulder of andesite has come from the Ochils. By the side of the stream west of Aberargie House, near Dunning, a large block of red sandstone, which has been striated lengthwise, has been transported from probably the further side of Strathearn. The shores all along the firth are strewn with boulders of dolerite and basalt derived from the sills and bosses lying to the north-west and west.

While dealing with the question of the distribution of material foreign to the district along the coast-line of Fife, we must bear in mind an important risk of error into which inexperienced observers may not unnaturally fall. So long as we have only to consider the erratics of the inland we are on perfectly safe ground. And even on the shore, when the boulders are of large size, weighing many tons, we are equally secure. But it must be remembered that a large quantity of foreign stones is every year brought to these shores by vessels from abroad. For many generations an active export of coal has been carried on from the Fife ports. The ships engaged in this trade often bring no cargo, but arrive in ballast, which they discharge. As they sail from all parts of the European sea-board, the blocks of stone which they bring represent the geological formations of various Continental countries. The trade is especially brisk with Scandinavia and the Baltic; hence an abundant assemblage of the rocks of that part of Europe has been strewn along the shores of Fife. Immediately to the west of the harbour of Dysart a great accumulation of this foreign material has been thrown down, and is now being distributed along the beach by waves and tidal currents. Abundant chalk-flints may indicate a trade with the south-east of England. But Scandinavia and the Baltic shores are unmistakably represented by the great variety of crystalline rocks. Those include various types of granite, gneiss, augen-gneiss, mica-schist, hornblende-schist, chloritic schist, phyllite, epidiorite, quartz-felsite, serpentine, and many more. There are likewise examples of the characteristic "sparagmite" of Norway and Sweden, while not improbably the volcanic geology of Iceland may be represented by large pieces of highly vesicular lava crowded with large and fresh olivine. This part of the shore may be commended to the attention of young petrographers, who will find here, within the compass of a few hundred yards of beach, a greater variety of rock-types than they could find in situ without many hundreds of miles of travelling.

(4) Sands and Gravels, Kame or Esker Series.—Over the low grounds that slope to the sea, and on the plains of the interior, extensive deposits of sand and gravel have been laid down upon the boulder-clay. These materials are well water-worn, and plainly indicate that the ice-sheet which produced the boulder-clay no

longer completely buried the country, but that running water carried along and laid down rolled shingle, gravel, and sand. But the ice had not entirely retreated; it still probably lingered upon the hills and even sometimes re-descended to lower levels.

The sands and gravels are much more restricted in their distribution than the boulder-clay. They ascend Strath Eden and the Howe of Fife, and pass westwards into the plain of Kinross, where they attain their chief development in this district, and whence they stretch westward into the basin of the Devon River. From the Eden Valley they may be traced through the hollows of the Ochil chain on the one side, and those of the Benarty, Lomond, and Kirkforthar Hills on the other. They fill the valley of the Leven up to its head or near it, and down to the sea across the lower ground by Markinch, Kennoway, and Largo. Over most of their extent they do not exceed a height of 450 feet above the sea, and are generally considerably below that level. In the plains of Kinross, where they form so wide an area, they keep generally below the 450-feet contour-line. Westwards, however, as they approach the Ochil Hills, they gradually rise towards these uplands until they reach a height of 800, and in the valley of the Queich Water even 1000 feet.

On the Kinross plain, the tendency of these deposits to assume the form of kames is most conspicuously exhibited. All round Loch Leven, but more especially in the tract stretching west from the lake to the Crook of Devon, the sands and gravels have been arranged in long, narrow, undulating ridges having a general east and west trend, and separated by narrow hollows which were once, no doubt, lakes, but are now filled with peat. One of the most persistent of these ridges, known locally as the Drungie Knowes, runs for about two miles, varying from only a few yards to 150 yards or more in breadth, and rising 30 or 40 feet above the plain on either side of it. Immediately below the sand and gravel, boulder-clay is to be seen wherever a cutting has been made, and its presence, even where no section reveals it, may generally be inferred from the stiff, retentive soil which overlies it. The presence of this impervious substratum here has no doubt served to retain the surface drainage, so as to give rise originally to many tarns and lakes, most of which have now disappeared.

(5) ANCIENT LAKES.—One important result of the general glaciation of the country was to leave numerous basins on the surface which, when the ice-sheets melted away, became filled with water and remained as lakes. These basins were of two kinds. On the one hand, some of them, especially those of smaller size among the high grounds, were scooped out of the solid rock by the long continued erosive action of the ice. On the other hand, by far the most abundant and largest owed their origin to the irregularities of surface left by the drift-deposits when the ice melted. Of the rock-basins, Loch Glow, among the Cleish Hills, is probably an example. Loch Leven is the most conspicuous instance of the other type.

Of the lakes left behind when the ice disappeared only a mere remnant is now extant. A vast number have vanished, partly from the natural processes of denudation and deposition, partly from having been drained by man. This subject will be more fully discussed in the following chapter.

There can be no doubt that both the remaining lakes of the region, as well as the large number which no longer exist, date back to the Glacial Period. Hence, if we could thoroughly explore the deposits left on the bottom of these existing and extinct sheets of water, we might expect to find in the lowest strata relics of the plants and animals which flourished at the time of the Arctic climate. One such exploration has fortunately been made, and it affords much encouragement to undertake other similar investigations. During the digging of the railway cutting at Dronachy, about a mile west of the village of Auchtertool, the bed of an ancient lake was laid open, and was carefully studied by Mr. James Bennie, of the Geological Survey of Scotland. Lying upon the boulder-clay for a distance of 300 yards a series of lacustrine deposits was found to present the following section:—

	Feet.	Inches.
(4) Surface soil	1	–
(3) Brown earthy silt, with *Lepidurus* (*Apus*) *glacialis*, *Salix herbacea*, *Betula nana* ...	3	–
(2) Marl with Lymnæa, *Pisidium*, &c.	1	6
(1) Running sand and mud	4 or 5	–

The marl (No. 2) with its fresh-water shells affords clear indication of the former presence of a lake on this spot, but throws no light on the climate of the time when this lake existed, for the shells are widely diffused species. But the silt (3) proves that the climate of Fife at that period was one of Arctic severity, for it contains remains of the Arctic willow and birch, together with a profusion of the remains of a small crustacean (*Lepidurus* or *Apus*) which is now confined as a living form to the fresh-water pools of Spitzbergen and Greenland, only thawed during the brief summer of those Arctic lands. Besides the plants above mentioned there were found also *Salix polaris*, *S. reticulata*, *Ranunculus aquatilis*, *Menyanthis trifoliata*, *Empetrum nigrum*, two species of *Potamegeton*, two species of *Scirpus*, and other plants. The animal remains included eggs of *Daphnia pulex*, jaws of a beetle, and portions of a spider. (For a list of the fossils found, see Appendix.)

(6) Raised Beaches and Terraces.—During the Glacial Period Britain stood for a time at a lower level above the sea than it does now. Its elevation was effected by an upward movement marked by several long pauses at different levels. These intervals of cessation or diminution of the upheaval are marked along the coast by terraces or platforms, of which two remain prominent in this district, the 100-feet and 25-feet beaches. These terraces are partly platforms cut by the sea out of the rocks of the land, especially out of the boulder clay, partly strips of sand, gravel, or clay deposited by the sea.

The 100-feet terrace or beach belongs to a time when the climate of the country was still Arctic, and when abundant glacier mud was carried down into the estuaries by the rivers that escaped from the melting ends of the ice. Hence the deposits of this highest terrace include characteristic finely-levigated clays ("gutta-percha clays") as well as sand and gravel. They are generally poor in fossils.

The inner edge of this terrace is often marked by a more or less steep bank cut out of boulder-clay, occasionally out of solid rock. The platform itself has suffered much from denudation, so that it exists only in fragments. But in this fragmentary form it may be followed along most of the coast of Fife. Beginning at the west end we find it well developed at Torry, where it runs for more than four miles up the valley of the Bluther Burn. Eastward it expands behind Torryburn, and then returns to within 300 yards of the present coast, with which it runs parallel for a short distance beyond Crombie Point. It can be easily traced here by the notch or shelf which has been cut out of the inland slopes of boulder-clay. To the west and north of Inverkeithing it stretches a long way inland. When the land stood a hundred feet lower the hilly ground about Inverkeithing and North Queensferry formed an island or group of islands, while the sea filled the valley followed by the line of railway between Dunfermline and Burntisland. The terrace can be traced at Aberdour, and again behind Burntisland. At the east end of King Alexander's Crag between Burntisland and Kinghorn the following succession of strata represents this terrace:—

Blown sand.
  Faintly-stratified sand, 3 feet.
  Dark black, stiff, sandy clay, 2 feet.
  Brown sandy and pebbly silt with angular stones at the bottom.
Basalt of the cliff, descending to the roadway.

The terrace is lost upon the rocky promontory of Kinghorn, but further north it comes out well as a level platform which stretches inland behind Kirkcaldy northwards to Pathhead. It is well displayed about Leven, whence it extends up the valley of the Leven River. Traced inland it appears in some places to shade away into the sandy and gravelly drift of the interior. Its best development in Fife, however, is to be found in the eastern districts from Largo round by Anstruther, Crail, and St. Andrews to Cupar, as will be more specially described in the Memoir on the East of Fife.

Here and there traces remain of the 50-feet terrace which forms so conspicuous a feature along the west coast of Scotland. But much of it appears to have been removed by denudation before the uprise of the next platform.

The 25-feet beach in the far north-west of Scotland was formed when the glaciers of Sutherland came down to the edge of the sea. In central Scotland, however, it was made by the sea long after the

ice had disappeared from the lowlands. It may be included here with the account of the Drift deposits, for it chronicles the last stage in that uprise of the land which took place mainly during the Glacial Period.

This terrace may be traced intermittently along the whole of the shores of Fife. Beginning at the extreme western border we find it presenting a distinct feature at Torryburn. Thence it runs to Crombie Point, passing by Charlestown and Limekilns, and generally keeping close to the present shore-line, sometimes retiring where it was once indented by a small bay, and again coming down close to the existing high-water mark. In some places the breadth of the terrace is so narrow as to leave little more than room for a roadway between high-water mark and the foot of the inland slope, as may be seen between Rosyth and Limpet Ness. Elsewhere even this scanty remnant has disappeared. There can be no doubt that, just as the 50-feet terrace was eroded, so large slices of this newer terrace have been cut away by the sea since the last rise of the land. Its soft sands and gravels offer but a feeble resistance to the waves, so that its breadth has been diminished, and even here and there it has been entirely removed, the present coast-line having been advanced into the area of the 100-feet terrace, and even beyond that limit into the higher ground behind. The general progress of the sea in the recession of the shores of Fife will be referred to in the following chapter.

The same terrace, as we follow it eastward, may be seen encircling the Inner Bay of Inverkeithing. It reappears in Dalgety Bay and in Barnhill Bay. At Burntisland, which is partly built on it, its position has been considerably obscured by blown sand. It forms the platform on which the lower or seaward parts of Kirkcaldy stand. It comes out again beyond the rocky coast of Pathhead and Dysart, and may be observed at Buckhaven, whence it stretches to Largo under links of blown sand. Its inner slope is often well defined by a steep slope of stiff, stony boulder-clay which marks the line against which the sea broke at high water when the land stood some 25 feet lower than it does to-day.

CHAPTER XIX.

Recent Deposits and Latest Changes.

In this chapter we may consider the youngest geological formations of the region, and the results of the latest geological changes which have taken place over the surface and along the coast-line of the country. It will be convenient to take note first of the effects of denudation in the deposition of alluvium along the margins of the streams, next the evidence for the infilling and disappearance of former lakes, and the influence of marshy vegetation in forming tracts of peat. We may then mark the results of wind-action in piling up tracts of blown sand along the shores, and lastly the proofs that the sea is making inroads on the land in some parts of the coast and making additions to the land in others.

River Terraces and Alluvium. — Most of the streams in Central and Western Fife and Kinross-shire, like those of the rest of the lowlands of Scotland, have one or more terraces which they have formed by the deposit of their sediment. In the great majority of cases there is only one such terrace, which forms the flat meadow or haugh through which a stream winds. Even the smallest burn will be found to present this common result of the action of running water. Where a stream descends from a slope to level ground its velocity and consequently its carrying power are lessened, and it throws down some of the sand and gravel which it was bearing from the higher land. Along the flanks of the Ochil chain many instances of such a cone of sediment may be observed. In like manner, where a stream enters a lake its capacity to transport sediment is checked, and its silt and sand sink to the bottom. Hence small deltas are formed, and the upper ends of the lakes are filled up with flat alluvium. Loch Fitty may be cited as a good illustration of this phase of the operation of streams.

But the larger streams not only present the usual flat meadow raised slightly above the surface of their waters and liable to be inundated in floods. They not infrequently display two or more terraces at higher levels. As the alluvial deposits of the rivers are expressed on the map by a pale yellowish tint which contrasts with the heavier colouring of the rocks underneath, it will be seen at once how each of the streams winds to and fro across an alluvial tract of its own making. The Eden, Leven, Ore, and Devon may be cited as illustrative examples. An examination of the deposits of one of these water-courses will show how the succession of terraces is formed. During floods, when the water, charged with mud and

sand, overspreads its "flood-plain," some of the sediment is left behind on the inundated ground. The water is checked in its flow by spreading over the flats, and part of its sediment is dropped, while more of the fine silt is arrested by the vegetation, which acts as a kind of filter. At the same time the stream may be busy scouring out its main channel. Hence in the end the water can no longer, even in flood-time, spread over the alluvial plain. But the erosion of its channel still goes on, and the banks are eaten away, now on one side, now on the other. The same process of inundation and deposit is repeated at a lower level. The old terrace is left, and a new platform is levelled out a few feet or yards beneath the old one. In this way a succession of alluvial terraces, marking former levels of a river in its gradual erosion of its valley, may be left rising one above another, and sloping gently with the same general inclination as the bed of the present stream.

The rivers of Fife are too small, rise from too low an elevation, and flow with too gentle a gradient to afford good illustrations of this process of erosion and deposit. The best examples will be found among the higher grounds, and especially in the course of the Devon and its tributaries which descend from the high ridges of the Ochils.

On a small scale no better instance can be quoted than one which may be seen in the Glendey Burn, the tributary which flows into the Devon down the valley described already at pp. 181, 183. The stream in this valley is only a small burn, but it descends from altitudes of between 1100 and 1200 feet, and has a fall of about 500 feet in less than a mile. It becomes a furious torrent in times of heavy rain, and has cut for itself a deep passage through the boulder-clay. In an early part of its history it flowed over a flat of that glacial deposit 150 feet above its present channel. At that time it spread out its debris from side to side as a layer of shingle and sand. But since then it has cut its way down through the boulder-clay, and now fragments of its old alluvium may be seen, on either side of the valley, 150 feet above the channel in which it at present flows.

The operations of the River Devon have been on a larger scale. This stream carries down the drainage of some of the highest ground in the Ochils. It has a swift current, and in times of spate sweeps down a large body of water and much sediment from the hills. When it began its history after the melting of the ice, it encountered a rock barrier at the present Rumbling Bridge. There may have been a ponding-back of the water there, with the consequent formation of a lake. The river began to spread out its alluvium at a height of 500 feet above the sea and formed a platform which is now to be seen in the flat alluvial terrace that runs eastward from the Rumbling Bridge. But in flowing over the rock-barrier it began to cut it down, and thus lowered the level of its own channel and laid bare the higher alluvial terrace. It then accumulated a second platform at a height

of about 450 feet above the sea, which exists as a well-marked terrace on the south side of the river between the Devil's Mill and Fossaway Bridge. By degrees the river has cut through the agglomerate a gorge, which at the Rumbling Bridge is 135 feet deep, and it is now spreading out its alluvium beyond the mouth of this ravine at a height of 300 feet above the sea. This picturesque piece of river-scenery is thus entirely the work of the Devon itself, and has been produced by uninterrupted erosion ever since the Glacial Period.

DISAPPEARANCE OF LAKES.—We have seen that the existing lakes of the region came into existence when the ice-sheets of the Glacial Period melted away, that they are only the last survivors of innumerable others which have disappeared, and that the same processes which have caused their extinction are still at work. The rains and streams which wash the disintegrated rock from the surrounding ground are continuously engaged in filling up the lakes, and we can, as it were, watch the process of extinction in its various stages. In the deeper lakes, its progress is slower, but in those that are shallow, the change can be appreciated even within the lifetime of one or two generations. When a lake is finally effaced, its place is taken by a flat sheet of alluvium. Not infrequently marshy vegetation has played a part in the conversion of the water into land; the lake has passed into the condition of a marsh before it finally became solid ground. The sites of such ancient sheets of water may be recognised by the black peaty soil which covers their flats of alluvium.

Many of the lakes of Fife and Kinross had no doubt passed away before historic times, by the natural play of geological forces. Since then many others have vanished partly or mainly by the help of man, who by draining them has turned their bottoms into fertile fields. In proof of the comparative rapidity of these topographical changes, reference may be made to the maps and descriptions of the ground that were prepared a century or two ago. It is interesting, for example, to compare Timothy Pont's map of Fife, published at Amsterdam as part of Blaeu's "Atlas" in the year 1662, with the present Ordnance Survey one-inch maps. The larger lakes are shown in both; a few appear on the modern map which, with other particulars of the topography, have been omitted by Pont, but the following list shows a number given by him which during the intervening two centuries have disappeared, their sites being now peat-mosses or alluvial plains under cultivation:—

"Dow Loch," north of Inverkeithing; its site is perpetuated in the name of the mansion-house of Duloch and the farm of Mid-Duloch.

"Carnok Loch," immediately to the east of Carnock Church.

"Black Loch," three miles north of Dunfermline, still exists, but is represented as having been much larger in Pont's time than it is now.

A lake is shown by Pont lying immediately to the south of Stevenson's Beath: this may have been a part of Moss Morran, then existing as a sheet of water surrounded by encroaching bog. No lake is to be seen there now.

"Loch Orr" (Inchgall Loch). This was a large lake, represented now by the alluvial plain, two miles long and more than half a mile broad, which stretches eastwards from the north end of the Kelty coal-field, and through which the River Ore flows in a straight artificial cut. The name of the vanished lake is preserved by the adjacent Lochore House. When this sheet of water existed the site of the ancient camp perched on the promontory of Chapel Farm must have been chosen for its easily defensible position, and Lochore Castle, now a ruin standing on a mere hummock in the midst of the alluvial plain, originally occupied an islet in the midst of the water.

"Bog Lochty"—the name given by Pont to a sheet of water which he places a little to the west of Kinglassie Village. It was probably, from its name, a morass in his time. It is now a drained and cultivated alluvial flat rather more than a mile long and from two to three furlongs broad.

"L. Balfarrig" is shown half a Scots mile to the north of Balbirnie. There is a farm still called Balfarg a little to the north of Balbirnie House; but Pont probably meant the site of the present Star Moss about a mile and a quarter to the east of that farm. Between the two places there is still a Lochmuir Wood.

"Loch Rossy." Next after Loch Leven this must have been the largest lake in this part of the country, for it covered an area of more than two square miles. Like Loch Leven, it lay among the mounds of the sandy drift. It has long disappeared, and is now represented by the alluvial flat which extends for nearly three miles close to the village of Auchtermuchty, with a breadth of about a mile. The River Eden flows along its southern edge.

"Swan Loch." This sheet of water appears to be now replaced by the small alluvial flat at Myreside, three miles south-west from Ferry-Port-on-Craig.

Historical evidence, though interesting and valuable, is not necessary for the purpose of mapping out the former lakes of Fife. A reference to the Geological Survey Map will show numerous alluvial tracts and peat-mosses which mark the sites of lakes. Thus the Star Moss north of Markinch represents an ancient sheet of water that lay in a hollow of the boulder-clay and sandy drift. It has been silted and choked up with marshy vegetation, which now forms a deposit of peat said to have an average depth of 20 feet. But beyond the limits of the moss a considerable tract of

surrounding alluvium indicates that the lake was of still larger size.

Again, Moss Morran may be cited as a peat-moss occupying the area of another lake, while to the north of Dunfermline a considerable number of former sheets of water are similarly indicated by flats of peat or alluvium.

Loch Leven supplies an interesting example of the union of the natural and artificial processes of denudation. By the cuttings made at the outlet of the lake the level of the water was lowered four and a half feet, and the millowners have the power of still further lowering it two and a half feet, which gives a total fall of the surface of the lake amounting to seven feet since the beginning of this century.

But this diminution is slight compared with that which the lake had undergone in earlier times by the action of its own outflow in cutting down the barrier at the south-east corner. The flat terraces around it, over which it once spread, rise to a height of at least 60 feet above the existing level of the water, and extend far beyond its present limits. The lake must once have been at least half as large again as it is to-day, for it spread from Milnathort to its exit at the defile of Auchmoor—a distance of six miles.

Loch Fitty has lost fully half a mile of its former length by the silting up of its upper end. The disappearance or diminution of the abundant sheets of water scattered all over Fife after the close of the Glacial Period is perhaps the most striking change which in the interval has taken place in the topography of the district.

Peat-Mosses.—As has been already mentioned, one prominent cause of the infilling and disappearance of the shallower lakes has been the gradual creeping of marshy vegetation over their surface. The plants as they die furnish a constant precipitation of peaty matter to the bottom. The growing plants convert the sheet of water by slow degrees into a marsh, and the marsh eventually becomes a peat-bog. Thereafter as the water is more and more excluded, the bog-plants die out and give place to heaths, and sometimes to willows, alders, and even to gorse and fir-trees. In this way the surface of Fife and Kinross was eventually dotted over with innumerable tracts of peat-moss. The same artificial causes which have led to the diminution of the number of the lakes have contributed also to the disappearance of the former abundant mosses. For generations peat continued to be the principal fuel even in the tracts where coal is now so plentiful and cheap. Large tracts of moss were thus deprived of their peaty covering and came in the end to be ploughed as arable land. Other areas where the peaty covering was thin were cultivated by being merely drained and ploughed, but the peaty nature of their soil may be readily recognised by the black colour of the fields when bare of vegetation in spring.

Considerable tracts of peat-moss, however, still remain to show how the surface of much of the region looked not many generations

ago. Some of them have been already alluded to in connection with the lakes which they have replaced, such as Moss Morran and the Star Moss. The largest continuous area of peat-covered ground is to be seen on the southern side of the Cleish Hills, where a succession of connected mosses covers a space about three miles long by two miles broad. Some of these tracts are known by special names, as the Din Moss, Black Rig Moss, and Tipperton Moss. Coal has so completely become the fuel of the whole district that little or no peat is now dug, except for use at the distilleries (p. 208).

Just as the lakes go back to the Glacial Period for their origin, so many of the accumulations of peat may have begun when the climate of the country was still Arctic. No absolute proof of this antiquity has yet been found in any of the peat-mosses of the district. But it is much to be desired that every fresh exposure of the bottom of a peat-moss should be carefully examined with the view of detecting traces of such an Arctic vegetation as that which was met with in the old lake of Dronachy already described (p. 186).

Blown Sand.—Along the estuary of the Forth, east of the narrows at Queensferry, the shores, where sandy and liable to be exposed and dried by the wind, are sometimes fringed with considerable tracts of blown sand. Above Queensferry the beaches are too much covered by the mud of the river to afford the necessary conditions for the blowing of sand inland. As far down as Burntisland, however, these conditions are fulfilled, and a patch of blown sand has there been accumulated across part of the raised beach on the links, against the southern front of King Alexander's Craig, and on the hill-slopes between Pettycur and Kinghorn. A more continuous strip of the same material stretches from Methil to Largo, and includes the links of Leven, Scoonie, and Lundin.

In the Firth of Tay, which is narrower, has more of a fluviatile character, and receives a far larger land-drainage than that of the Forth, the space between tide-marks is mainly overspread with mud. Consequently no accumulations of blown sand are there possible. It is not until the estuary opens out beyond Broughty Ferry, and the action of the open sea comes into play in scouring the coast and spreading out wide sandy flats below the line of high water, that sand-dunes can be formed in that part of the country.

In connection with the drifting of sand along the shore, allusion may here be made to the effects of this action on the rocks over which the sand grains are driven by the wind. The surfaces of even the hardest rocks are smoothed, polished, and worn into fine irregular ruts and grooves trending in the direction in which the wind blows. Some beautiful examples of the results of this process may be seen to the west of Pettycur where the spurs of the basalt-cliffs descend upon the beach. Every knob and face of rock within two or three feet above the surface of the sand has been worn down in this way by the prevalent blasts from the south-west.

Action of the Sea on the Coast.—Even within the comparatively sheltered limits of an estuary, such as that of the Firth of

Forth, the waves are making noticeable progress in the wasting of the coast-line. On the shores of Fife at many places the progress of this destruction may be watched. Fortunately the barriers opposed to the sea consist mainly of solid rocks, so that the rate of waste is comparatively slow. But that the land is in many parts losing ground may be seen in the projecting cornice of soil and turf which often overhangs the rocks below, and of which large recently detached fragments may sometimes be found lying on the beach below. Where the waves have had only the boulder-clay, or still more the incoherent deposits of the last raised beaches, to oppose their advance, the rate of destruction has been much more marked. Hence only fragments of the twenty-feet beach have survived. On the more exposed situations, this terrace has been entirely cut away. There is historical evidence of part of the progress of this destruction. Thus before the 17th century the grassy links which cover the twenty-five-feet terrace are said to have reached as far as the Black Rocks, half a mile from the present shore at Burntisland.* But all that extent of ground has for several generations been covered by the sea at high water, and but for the protection of a strong embankment, the terrace would doubtless ere now have been still more reduced.

The action of the sea along the shores of Fife is not all of a destructive nature. In favourable localities the waves cast ashore the sediment they have derived from the waste of other places. Unfortunately the balance is largely on the side of loss. Where blown sand accumulates we may generally infer that no serious erosion is in progress, but that the sea provides a protection against its advance by drifting sand to these parts and supplying the material that is blown inland by the wind. In certain places the land may thus actually be gaining instead of losing.

The material accumulated by the sea along its margin is classed together under the name of Marine Alluvium. The character of this material constantly varies according to the nature of the sources from which it is derived and the force of the waves and currents by which it is carried and deposited. In the estuary of the Forth above Queensferry, the alluvium consists chiefly of the mud brought down by the Forth, Carron, and other streams. Large tracts of this soft, tenacious mud or "slob" may be seen fronting Torryburn, Charlestown, and Rosyth. In the Firth of Tay, as already remarked, the muddy type of marine deposit is still more abundantly represented. Below Queensferry, however, where the Firth of Forth opens widely to the influence of winds, waves, and tidal currents, much greater variety of material is laid down by the margin of the land. Though the estuarine mud may be found in patches even as far east as Kirkcaldy, the finer sediment is generally sand, and becomes cleaner the further east it is examined.

* Sibbald's "Fife and Kinross" (1710), p. 152. A. Geikie's "Scenery of Scotland," 3rd Edit., p. 59. The waste of the shores of Fife will be more fully discussed in the Memoir on Eastern Fife, where the proofs are still more abundant.

One of the largest tracts of tidal sand has been gathered into the recess of the coast between Burntisland and Pettycur. A sandy beach fronts the shore from Tyrie to Pathhead, and again from Methil to near Largo. As the shores are not exposed to any long "fetch" of the waves, there are no prominent storm-beaches of coarse shingle. Most of the shores are strewn with boulders derived from the waste of the boulder-clay.

CHAPTER XX.

Economic Minerals.

THE county of Fife has long been noted for the abundance and variety of its useful minerals. Throughout its whole length, from near St. Andrews to its western border, coal and ironstone are abundantly distributed, and have long been worked. The sandstones of the Carboniferous system furnish excellent building stone. The same series of strata supplies limestone, fire-clay, and oil-shale. From the general diffusion of igneous rocks through the region, varieties of road-metal are to be found in every district. Among the superficial deposits brick-clay, shell-marl, sand, gravel, and peat are obtainable in different parts of the county.

In the present chapter some details will be given regarding the industries connected with these various groups of mineral substances. We shall begin with the most important industry, that of coal-mining. In previous pages an account has been given of the succession of strata and general geological structure of the various coal-fields. We have now to deal with the coals from an economical or commercial point of view. The following particulars regarding the seams at the different collieries have been collected and arranged by Mr. J. S. Grant Wilson from information supplied to him by the lessees and proprietors:—

Coal.

Name of Colliery.	Name of Coal.	Thickness. Ft.	In.	Quality.	Class.
Blairadam Colliery, (Fife and Kinross Coal Co.)	Main Coal.	6½		Good.	Steam.
	Kinglassie Splint.	4⅓		Fair.	Splint.
	Coal (not identified).	3⅔		,,	,,
	Coal (not identified).	3½		Good.	,,
Bowhill Colliery,	Duddy Davie Coal.	5	5	Poor.	Steam.
	Lochgelly Splint Coal.	5		Good.	Good Steam, 2nd class Household.
	Lochgelly Parrot Coal.	2½		,,	Gas.
	Five-foot Coal.	4		,,	2nd class Household.
	Dunfermline Splint Coal.	4		Excellent.	Best Household.
Cowdenbeath Colliery,	Lochgelly Splint and Parrot Coal. Foul Coal.	2		...	
	Splint Coal.	5		...	
	Fire-clay.	1		...	Household Coal.
	Coal.	–¾		...	
	Parrot Coal.	2		...	Gas Coal.
	Coal.	1¼		...	Household Coal.

Name of Colliery.	Name of Coal.	Thickness.	Quality.	Class.
		Ft. In.		
Cowdenbeath Colliery —*continued.*	Mynheer Coal.	4½	...	Steam and Household.
	Five-foot Coal.	5	...	Steam and Household.
	Dunfermline Splint Coal.	5 –	...	Household.
Donnibristle Colliery,	Lochgelly Splint.	7 –	1st class.	Steam.
	Lochgelly Parrot.	4½ –	,, (and 2nd	,, class Cannel).
	Mynheer Coal.	5 – to 7 –	Good.	Household.
	Five-foot Coal.	4⅚ –	2nd class.	,,
	Dunfermline Splint Coal.	4⅝ –	1st class.	,,
	(There are three third-class seams of steam coal at this colliery which have not been worked.)			
Dundonald Colliery,	Smithy Coal.	3 –	Ordinary.	Steam.
	Fourteen-foot Coal (Upper Leaf).	2⅝	Good.	Household and Steam.
	Fourteen-foot Coal (Lower Leaf).	6 –	Fair.	Steam.
	Duddy Davie Coal.	2¾ –	Good.	Household and Steam.
	Lochgelly Splint Coal.	4¼ –	Very good	Household.
	Lochgelly Parrot Coal.	2¾	,,	,, (Splint).
	Glassee Coal.	3¼	Good.	Household and Steam.
	Mynheer Coal.	2¾	Very good	Household.
Dunnikier and Begg Collieries,	Rough Coal.	3½	2nd class.	Steam (Cherry).
	Black Coal.	3	1st ,,	Steam and Household.
	Parrot Coal.	2	2nd ,,	Gas Coal.
	Glassee Coal.	3½	1st ,,	Steam (Cherry).
	Mynheer Coal.	2	2nd ,,	Smithy Coal.
Fordel Colliery,	Lochgelly Splint Coal.	5½ – to 6½	Good.	Household and Steam.
	Lochgelly Parrot Coal.	3¾ to 4⅙	,,	Household and Steam, with 6 to 8 in. Parrot and Steam.
	Blawlowan Coal.	4½ to 7	Fair.	Steam.
	Mynheer Coal.	3⅜ to 4½ –	Good.	Household and Steam.
	Five-foot Coal.	4 – to 5 –	,,	Household and Steam.
	Dunfermline Splint Coal.	4 – to 4½ –	,,	Household.
Halbeath Colliery,	Cairncubbie Coal. Upper Leaf.	1 5	Friable, cherry.	Fair Steam.
	Cairncubbie Coal. Lower Leaf.	1 11	Splinty, hard.	2nd class Household.
	Upper Eight-foot Cool.	3 4	Splinty, hard.	,,
	Lower Eight-foot Coal.	3 9	Not so hard.	,,

Name of Colliery.	Name of Coal.	Thickness. Ft.	In.	Quality.	Class.
Halbeath Colliery—*continued.*	Upper Five-foot Coal.	3 to 6		Bright, soft.	Good Steam.
	Lower Five-foot Coal.	5	1	Partly splint & soft.	1st class Steam, 2nd class Household.
	Dunfermline Splint Coal.	3	9	Hard splint, with soft portion.	1st class Household.
Hill of Beath and Dalbeath,	Fourteen-foot Coal.	4	8	...	Steam.
	Duddy Davie Coal.	5	5	...	,,
	Lochgelly Splint Coal. Coal.	4	2	...	,,
	Lochgelly Splint Coal. Stone.	1 to 3	–	...	,,
	Lochgelly Splint Coal. Coal.	3	9	...	,,
	Glassee Coal.	5	5	...	
	Five-foot Coal. Ironstone.	–	8	...	
	Five-foot Coal. Coal.	5	–	...	,,
	Dunfermline Splint Coal.	4	6	...	Household.
Kelty Collieries,	Main Coal. Roof Coal.	1	10	Good.	Bunker Coal.
	Main Coal. Good Coal.	4	8	...	
	Jersey Coal. Coal.	2	6	Good.	Steam.
	Jersey Coal. Stone.	2	4	Good.	Steam.
	Jersey Coal. Coal.	3	8	Good.	Steam.
	Bank Coal (Lochgelly Splint).	4	5	,,	Steam and 2nd Household.
	Five-foot Coal.	5		,,	Steam and 2nd Household.
	Dunfermline Splint.	4	7	,,	Best Household.
Kinglassie Coal-field,	No. 1 Coal.	3	–	...	
	No. 2 Coal (Leven 6 ft.).	5	5	Good.	Household.
	No. 3 Coal.	$4\frac{3}{4}$		,,	,,
	No. 4 Coal.	5		...	
	No. 5 Coal.	$2\frac{2}{3}$		...	
	No. 6 Coal (Muiredge 4 ft.).	$4\frac{1}{3}$		Good.	,,
	No. 7 Coal.	$4\frac{3}{4}$		,,	Good Household.
	No. 8 Coal.	$3\frac{3}{4}$		...	
	No. 9 Coal. BB Ironstone.	$1\frac{2}{3}$	–	...	
	No. 9 Coal. Coal.	$2\frac{1}{6}$	–	...	
	No. 10 Coal.	4	–	...	
	No. 11 Coal (Dysart Main).	18	–	Soft.	Inferior Steam.
	No. 12 Coal.	4	–	...	
Lassodie Colliery,	Six-foot Coal.	3	6	1st class.	Household and Steam.
	Cairncubbie (Upper Leaf).	4	–	,,	,,
	Eight-foot Coal.	5	–	,,	,,
	Five-foot Coal.	5	–	,,	,,
	Dunfermline Splint Coal.	4	6	,,	,,
Lassodie Mill Colliery,	Main Coal.	4	–	2nd class.	Household.
	Cairncubbie Coal.	$3\frac{1}{4}$		1st class.	,,
	Bank Coal (Lochgelly Splint).	5		2nd class.	,,
	Glassee Coal.	5		,,	Steam.
	Mynheer Coal.	3		,,	Household.
	Five-foot Coal.	$5\frac{1}{2}$		,,	,,
	Dunfermline Splint Coal.	$4\frac{1}{4}$	–	1st class.	,,
Leven, Durie, and Wollsgreen Collieries,	Eight-foot Coal. Roof Coal.	$1\frac{1}{2}$	–	...	Steam.
	Eight-foot Coal. Good Coal.	$5\frac{1}{4}$	–	...	Steam.

Name of Colliery.	Name of Coal.	Thick-ness.		Quality.	Class.
		Ft.	In.		
Leven, Durie, and Wellsgreen Collieries —*continued.*	Six-foot Coal. Coal.	1½		...	Steam.
	Stone.	–¾		...	
	Coal.	2⅓		...	
	Chemiss Coal. Crow Coal.	1		Not worked.	
	Parting.	–	1½	...	
	Splint Coal.	3⅓	–	...	Good Household.
	Parting.	–	1	...	
	Binks Coal.	2⅓	–	...	Steam.
	Stone.	–⅔	–	...	
	Coal.	1½	–	...	Steam.
	Parrot Coal.	3		...	Gas Coal.
	Dysart Main Coal. Coal.	2	–	Not worked.	
	Stone.	–	1½		
	Coal.	–½	–		
	Stone.	–	2		
	Coal.	1⅙	–	Worked.	Steam.
	Stone.	–	5		
	Coal.	3⅓	–		
	Stone.	–¾			
	Coal.	3⅙	–		
	Stone.	·	1		
	Coal.	–½	–		
Lochgelly Colliery,	Little Splint Coal.	3	–	Good.	2nd class Steam.
	Fourteen-foot Coal.	10	–	,,	,,
	Duddy Davie Coal.	3	–	,,	,,
	Lochgelly Splint Coal.	5	–	,,	1st class Steam.
	Lochgelly Parrot.	3¼	–	,,	2nd class Gas Coal.
	Glassee Coal.	3		,,	2nd class Steam.
	Mynheer Coal.	3¼	–	,,	1st class Household.
	Five-foot Coal.	4	–	,,	1st class Steam.
	Dunfermline Splint Coal.	4	–	,,	1st class Household.
Lochore and Capledrae Colliery,	Capledrae Gas Coal.	2 to 3		1st class.	Top of Seam — Gas Coal.
				2nd class.	Bottom of Seam — Gas Coal.
Lumphinnans Colliery,	Lochgelly Splint and Parrot Coal. Foul Coal.	2	–	...	
	Splint Coal.	5	–	...	Household Coal.
	Fire-clay.	1	–	...	
	Coal.	–¾	–	...	
	Parrot Coal.	2		...	Gas Coal.
	Coal.	1¼	–	...	Household Coal.
	Mynheer Coal.	4	–	...	Steam and Household.
	Five-foot Coal.	4½	–	...	Steam and Household.
	Dunfermline Splint Coal.	4		...	Household.
Muircockhall Colliery,	Six-foot Coal.	5½	–	Fair.	Steam.
	Cairneubbie Coal.	3½	–	,,	2nd class Household.
	Three-foot Coal.	3	–	,,	Steam.
	Eight-foot Coal.	4½		,,	,,
Muiredge, Denbeath, Rosie, and Cameron Collieries,	Eight-foot Coal.	5 to 6	–	Splint and cherry.	Household and Steam.
	Six-foot Coal.	6	–	,,	Steam.

Name of Colliery.	Name of Coal.	Thickness.	Quality.	Class.
		Ft. In.		
Muiredge, Denbeath, Rosie, and Cameron Collieries—*contd.*	Chemiss Coal.	7 – to 8 – 8 to 6	Splint and free.	Household and Steam.
	Parrot Coal.	1½ to 2½	Ironstone and cannel.	Gas Coal.
	Dysart Main Coal.	9 to 10 –	Cherry and splint.	Household and Steam.
Muirheath Colliery,	Six-foot Coal.	3 –	Good.	Steam.
	Cairncubbie Coal.	4½ –	,,	2nd class Household.
	Three-foot Coal.	4 –	,,	Gas Splint, 6 in. 1st class Cannel on bottom of Coal.
	Eight-foot Coal. Upper Leaf.	3 3	,,	Steam.
	Eight-foot Coal. Under Leaf.	4 3	,,	
	Five-foot Coal.	5 –	,,	Steam.
	Dunfermline Splint Coal.	3½ –	,,	1st class Household.
Oakley Steam Colliery, Oakley, Kineddar,	Five-foot Coal.	3 –	Very good	Steam.
	Kineddar Splint Coal.	3½ –	Fair.	Household.
Rosebank Colliery, (Dunfermline).	Upper Eight-foot Coal in two leaves, each from	2 to 2 6	...	Steam and Caking.
	Upper Swallowdrum Coal.	4 – to 4 6	...	,,
	Lower Swallowdrum Coal.	4 – to 4 6	...	,,
	Under Eight-foot Coal in two leaves, each from	3 – to 3 8	...	,,
	Five-foot Coal.	3 – to 4 6	...	Steam.
	Two-foot Coal.	2 – to 2 3	...	,,
	Four-foot Coal.	2 to 2 6	...	,,
Rosewells Colliery,	Brown Cannel.	–⅔ –	2nd class.	Gas Coal.
	Boghead Cannel. (This is the Capledrae Gas Coal.)	$2\frac{1}{12}$ –	1st class.	,,
Steel-end Mines, Saline,	Eight-foot Coal.	6 –	Inferior.	Steam.
	Three-foot Coal.	3 – to 4 –	Very good	,,
	Coal.	2½ – to 2¾	Good.	Steam and Smithy.

Name of Colliery.	Name of Coal.	Thickness.	Quality.	Class.
		Ft. In.		
Steel-end Mines, Saline —*continued.*		4 6	Bastard Parrot.	
		Coal 1½ –	...	
	Parrot Coal.	Fire-cl'y 1½ –	...	
	Five-foot Coal.	Coal 1⅔ to 2½	Fair.	Steam.
	Two-foot Coal.	...	...	
	Splint or Four-foot Coal.	...	...	
Townhill Colliery, (Dunfermline).	Bride Coal.	4¼ –	Fair to good.	Splint and Steam.
	Six-foot Coal.	4 –	Good.	Steam.
	Cairneubbie Coal.	2⅔ –	Excellent.	Household.
	Swallowdrum Coal.	4⅙ –	Fair to poor.	Steam.
	Ell Coal.	2⅔ –	Poor.	,,
	Upper Eight-foot Coal.	3¼ –	Fair.	,,
	Lower Eight-foot Coal.	3½ –	,,	Household.
	Five-foot Coal.	5 –	Excellent.	Steam.
	Dunfermline Splint Coal.	4½ –	,,	Household.

Ironstone.

The iron-ores obtained in Fife occur as beds or as nodules of argillaceous carbonate of iron intercalated among the shales and coal-seams of the Carboniferous system. The most valuable, known as Black-band, contain a considerable admixture of carbonaceous material and can readily be calcined. A more abundant but less valuable kind, called Clay-band, is plentiful among the black shales in nodular concretions ("balls"), in thin partings and in thicker seams. It contains little of the carbonaceous ingredient of the Black-band, and thus requires more coal in its calcination. Only the first variety is worked in Fife at present, and to a less extent than formerly, some of the blast-furnaces having been disused and even removed.

Locality.	Thickness.	Class.	Quality.
Lochgelly and Lumphinnans Collieries, (Not worked at present. The furnaces at these two collieries are not now in blast.)	2 ft.	Black-band Ironstone.	2nd class.
Hill of Beath and Dalbeath (Fife Coal Co.), (The Stone on the top of the Five-foot Coal is at present worked.)	8 in.	Black-band.	2nd class.

Locality.	Thickness.	Class.	Quality.
Halbeath Colliery (Kingseat Pits), . (The upper part of Lower Five-foot Coal.)	6 in. to 8 in.	Black-band.	2nd class.
Kinglassie Coal Field, . . (Worked about 30 years ago.)	1 ft. 8 in.	Black-band.	...
Tillybreck Pits (Wemyss Estate), . (Worked about 40 years ago.)	2 ft.	Clay-band.	Good.
Kilmure Colliery (North of Kennoway), (Worked from 1870 to 1872.)	1 ft. 6 in. to 2 ft.	Black-band.	Good.

With the ironstones that have been mined as a source of the metal may here be included those earthy varieties which have been worked chiefly as materials for pigments. The most notable of these is the Ochre referred to on p. 159 as occurring in the red measures at the top of the Carboniferous system of Fife. It is a yellow, soft, decomposing material, consisting of clay or fine sand largely intermixed with hydrous ferric oxide. Three beds of this substance may be seen in the coast-section west of Drumochy, and one lies about 117 fathoms above the Chemiss Coal on the shore to the west of Methil. The seam which lies 60 fathoms above that coal-seam was worked to a considerable extent about 40 years ago in the neighbourhood of Leven. It was reached by a day-level at the foot of Muiredge Den, and also by a pit situated 300 yards to the north-east of the old Scoonie Pit. The grinding mills were in Leven, and the ground pigment was shipped to Leith for sale. The following remarks on this material, which is not now worked in the district, are taken from Landale's "Geology of the East of Fife Coal-field." * "The ochre is next seen and wrought a little north from Methil, after being thrown forward by the fault E. It is then wrought north from the town of Leven, after being thrown forward by the fault; and lastly it is seen above the coals at Drumochy. This peculiar substance, so extensively used as a pigment, has not, to my knowledge, been analysed. It appears to be a very fine clay or shale, coloured bright yellow by oxide of iron. It is a most variable substance; sometimes it diminishes in thickness to three or four inches, and then swells out again to as many feet. It is very difficult to be got free of sand, which renders it nearly useless. At Wemyss Castle it is not sufficiently coloured for use; at Buckhaven it approaches to the nature of sandstone; at Methil it is sometimes pure, and a few yards farther it is

* Prize Essays and Transactions of the Highland and Agricultural Society of Scotland. Vol. XI. (1837), p. 279.

impregnated with sand; to the north of Leven it is even more irregular; and at Drumochy it is quite arenaceous and useless."

Another ore of iron, which occurs in Kennoway Den, is a good hæmatite from nine inches to a foot in thickness, which was worked about 30 years ago by means of an "ingoing eye." It has a fine red colour, and was shipped to England as reddle or keel for marking sheep.

Galena.

In various parts of Fife, veins or strings of galena have been met with, some of which have been worked, but none of them appear to be sufficiently thick and persistent to be worth further exploration. Dr. Heddle states that "many years ago a vein of galena was worked at Blebo [a few miles to the south-west of St. Andrews], and another near North Queensferry, where it occurred in fine cubo-octahedral crystals. It is accompanied by small quantities of blende at the first of these localities." *

Another vein occurs at Hanging Myre, half a mile to the south of the summit of the East Lomond Hill. The trend of the lode is from south-west to north-east. It cuts the limestone which has there been quarried, and runs into the hill at the farm-house. No record has been found of the workings, but in Buist's manuscript Geology of Fife the following information is given:—"The mine was wrought in 1780 by Stewart of East Conland for galena and silver. A considerable quantity of metal was smelted on the spot and silver said to have been extracted. Six tons of ore were sent to Perth for shipment. The vein runs N.E. and S.W. through sandstone and limestone."

Fire-Clay.

Throughout the coal-bearing portions of the Carboniferous system of Fife seams of fire-clay are frequent intercalations. A good many of these are worked, but many more are available for future use. The following list comprises some of the more important seams at present employed for the manufacture of bricks, pipes, and various kinds of sanitary appliances:—

At Townhill Colliery, Dunfermline, a parting of fire-clay in the Swallowdrum Coal has a variable thickness from 10 inches to several feet. It is of good quality, and is made into bricks and pipes. But it is only taken out in order to work the overlying coal.

At Lochead, to the north of Dunfermline, a large fire-clay work has long been established, where all classes of bricks, pipes, and sanitary goods are manufactured. The stratigraphical position of the seam of fire-clay, which is here wrought on the ground, is not certain. It occurs on the south side of the Loch Fitty fault, and the pit-workings to the south show the ground to be very much "troubled" by numerous faults.

* "Fife: Pictorial and Historical," p. 21.

The Fife Coal Company have an extensive manufacture of bricks, pipes, fire-bricks, and sanitary goods at Hill of Beath. The clay used there is partly brought from the company's Durie Colliery, Leven, taken from under the Eight-foot Coal, there 18 inches thick, and partly from the Fourteen-foot Coal at Hill of Beath, where a fire-clay 15 inches thick forms the roof of that coal.

At Dundonald Colliery, Cardenden, a bed of fire-clay 3 feet thick lies above the Glass Coal. It is not worked at present, but was formerly used for fire-bricks.

The Wemyss Coal Company employ the Burncraig seam, which is of good quality, for the manufacture of bricks.

At Muiredge, Buckhaven, the Six-foot Coal is separated into two leaves by a band of fire-clay of fair quality from 18 to 24 inches thick, which is employed in the manufacture of good hard bricks, sewage pipes, vent-linings, chimney-cans, &c.

At the Kingseat pits of the Halbeath Colliery a seam of good fire-clay 1 foot thick lies underneath the Cairncubbie Splint Coal, and is used for making fire-bricks. With the Upper Five-foot seam a bed of excellent pipe-clay 2 feet 9 inches thick is employed for the manufacture of pipe-clay goods.

Oil-Shale.

Bituminous shales which can be used for the distillation of mineral oil occur in different parts of the Carboniferous series of Fife. They were formerly mined to a considerable extent, but the fall in the price of oil and the residual products has led to the abandonment of this part of the mineral industries of the district. The shale above the Burdiehouse Limestone at Binnend, Burntisland, was extensively worked by three principal mines, of which the longest extends northwards for a distance of 900 yards. The works, which were closed about ten years ago, manufactured crude and refined oil, "scale," and sulphate of ammonia. The "scale" was made into candles in the factory at Kinghorn Loch.

The same or a similar seam of oil-shale runs westward with the crop of the limestones, and is seen on the declivity at the north end of Whitesands Bay. An oil-shale, believed to be the Dunnet seam of the Lothians, has already been referred to as seen to the north of St. Davids. There can be little doubt that should the price of mineral oil rise sufficiently to warrant further search in this district, workable tracts of oil-shale might be found in the tract between Burntisland and Inverkeithing, though no doubt much of the material has been destroyed by the intrusive igneous rocks which there abound.

Another dismantled oil-work, where oil was made from a much higher horizon in the Carboniferous rocks, may be seen at Westfield, Kinglassie. At the base of that coal-field, 26 fathoms below what is believed to be the Dysart Main Coal, and 1 fathom above the Levenseat Limestone, a seam of Parrot Coal 4 feet thick is surmounted by 2 feet 8 inches of foul soft coal. This

Parrot seam was mined and distilled here about 18 years for the production of crude oil. Throughout the coal-fields seams of bituminous shale and coal, which are not now worked, might be mined for the manufacture of oil, if a sufficient and permanent rise in the price of the commodity were to take place.

Building-Stone.

There is an inexhaustible supply of good building-stone in the county of Fife. Most of it is to be found among the thick intercalations of sandstone in the Carboniferous system. Some of these bands consist of excellent freestone, capable of being cut in any direction, and therefore well suited for architectural purposes. The most close-grained, firm, and durable stone is to be met with in the Burdiehouse Limestone group, which is chiefly developed between Burntisland and Inverkeithing. The quarries of Grange, Kilmundy, and Cullalo have long been known, but new openings might be made in almost any part of that ground.

The sandstones of the other divisions of the Carboniferous series are, on the whole, softer, more open in texture, and coarser in grain, so that they are less well adapted for polished ashlar-work, but they yield good material for the construction of walls.

The Carboniferous sandstones are generally grey, white, or yellow. In parts of the Millstone Grit group they have a purplish-red tint, and in the highest sub-division of the series from Wemyss to beyond Leven they are generally of a brick-red colour.

The Upper Old Red Sandstone contains some good red freestone, which has been worked in quarries between Loch Leven and Cupar.

The abundance of sandstones in the district, their excellent quality, and the ease with which they can be dressed have led to their being almost the only building-stones made use of. But many of the igneous rocks are capable of being employed for some of the same purposes. Though these materials cannot be dressed freely on account of their hard, splintery character and abundant concealed joints, they have been largely quarried for walls and field-fences. Where they are close-grained and can be split along clean, smooth joints they can be substituted for freestone even in the front walls of houses. Some of the dolerites and basalts are more particularly serviceable for such a purpose. Occasionally also the coarse-grained dolerites can be quarried in large quadrangular blocks suitable for piers and harbour works, where strength and durability are required. The great sill of Queensferry is an example of this kind of stone.

Limestone.

The county of Fife possesses an ample store of limestone. In former years, when it was the practice to make much more abundant use of lime in agriculture than is now the case, lime-quarries and kilns were at work all over the region. Most of these are now disused.

Considerable variety in the nature of the stone marks the different seams of this material. The lowest in stratigraphical position is the Cornstone described in Chapter V. It is a somewhat sandy and siliceous limestone, and was formerly extensively worked along the northern slopes of Benarty Hill. It could be obtained in large quantity from its outcrop between Mossendgreen and Muckart near the Rumbling Bridge.

The Cement-stone group, as its name denotes, includes bands and nodules of argillaceous and ferruginous limestone from which cement can be manufactured. This group, however, is not well developed in the West of Fife. Its calcareous members are best displayed in the valley of the Devon at Muckhart Mill.

The Burdiehouse Limestone group includes a number of seams of limestone, of which the thickest and most valuable has long been worked between Burntisland and Aberdour. This seam is a remarkably fine-grained and pure limestone, well suited as a flux for iron-furnaces. Unfortunately it is confined to the limited tract of ground between Dodhead and Whitesands Bay. It was formerly worked open-cast, but it is now mined and removed by railway. As explained at p. 46, there are several bands of the limestone intercalated among sandstones and shales, but it is the thickest of them which is worked.

The Carboniferous Limestone series includes numerous bands of limestone, from the Hurlet seam at the base to the Levenseat seam at the top. The Hurlet is the thickest and on the whole most valuable band. It has formerly been extensively worked along its crop, and is still largely quarried at a few places. Some of the most extensive openings in it are to be seen at Charlestown, Roscobie, Chapel, north of Leslie, and south of Pitlessie. The Hosie Limestones have also been worked on a considerable scale. Their general characters can be conveniently seen in the shore section east of Seafield Tower.

The higher limestones are seldom to be seen at the surface owing to the covering of drift. The best sections of them are those on the coast east of Pathhead, where the two highest, the Gair and Levenseat seams, are exposed (*ante*, pp. 133–137). These limestones, being thinner and more impure than the Hurlet seam, have not been generally opened up for industrial purposes.

Road-Metal.

Owing to the abundance of igneous rocks distributed all over Fife, materials for the construction and repair of roads are almost everywhere obtainable. These rocks vary greatly in their hardness and durability. In general they decay for a distance of less than an inch up to several feet or yards from the outer surface, so that their true characters are not always to be judged of from the shallow exposures of them to be seen in roadside quarries, and still less from the weather-beaten crags in which they so frequently rise above ground.

The amygdaloidal andesites of the Ochil Hills have frequently a weathered outer layer which can be easily dug or picked away, and

which without further treatment is available for road purposes. More durable are the solid, undecayed, and least amygdaloidal portions of these rocks when broken up into fragments. But the porphyritic and non-amygdaloidal varieties, both of the lavas and sills, supply the best road-making materials. Excellent examples of these rocks may be seen at Newburgh and in Glen Farg. None of them, however, possesses qualities sufficient to make them sought after for more than merely local demand. It will be seen that the whole of the northern half of Fife can be supplied from this source. Quarries may be opened almost anywhere on the andesite ground close to some road, so that the material is accessible with no great cost of transport.

The tuffs scattered in separate patches over Fife are not well adapted for roads: they are too crumbling, and soon get crushed into dust and mud under wheel-traffic.

Undoubtedly the best materials for road-construction are the various basalts and dolerites so abundantly distributed in sills, bosses, and dykes. The advantages of these rocks, from their durability, accessibility, and ease of working, have long been recognised in the district, and innumerable quarries have been opened in them, chiefly for local use. Some of them, however, are suitable for wider sale. The great dolerite sill of North Queensferry has long been worked on an extensive scale, its closeness to the shore facilitating its shipment to a distance. The extent to which Fife has now been opened up by railways has brought almost every part of the county within reach of the shipping ports. It is probably not too sanguine an anticipation to look forward to a time when some of the innumerable masses of basalt and dolerite of the interior will be turned to account for more than merely local consumption, and will be shipped to some of the great towns of the country for causeways and kerbstones.

Peat.

Until the development of the coal-fields, peat was the general fuel used in Fife, as in the rest of Scotland. Much of the old mosses has disappeared, though, as described in the previous chapter, a few tracts remain as memorials of what was once the condition of many of the lower levels of the region. Peat is still dug in a few places, as at Moss Morran in the parish of Beath, and at the Star Moss in the parish of Kennoway. It is chiefly employed in the distilleries to give the peculiar smoky flavour to whisky.

Shell-Marl.

The beds of some of the vanished lakes are underlain with a deposit of lacustrine shells, forming a marl which was once sought after as a manure for soils. A layer of this nature, from two to three feet deep, and covering an area of twenty acres, occurs at Inchrye, a little south of Newburgh, and other examples have been noted in different parts of the county.

APPENDIX.

PART I. PALÆONTOLOGICAL.

Note by B. N. Peach.

A. List of Localities from which fossils have been obtained.

B. General List of Fossils arranged in their systematic order.

C. Special Lists of Fossils found in each of the subdivisions of the Stratigraphical series.

PART II. PETROGRAPHICAL.

PART III. BIBLIOGRAPHICAL.

PART IV. JOURNAL OF BLAIRHALL BORE, OAKLEY.

APPENDIX.

PART I. PALÆONTOLOGICAL.

The first collection of fossils from Fife and Kinross, made by the Geological Survey, consisted of specimens gathered by the late R. Gibbs and named by J. W. Salter. Lists of Carboniferous fossils, based on this collection, were inserted on the margin of Sheet 40 of the One-inch Map, which was published in 1867. Only a few of the specimens from which these lists were drawn up have been available for the purposes of this Appendix.

Most of the fossils enumerated in the following lists were collected by Mr. James Bennie, and were determined by Mr. R. Etheridge, jun., when acting as Palæontologist to the Geological Survey of Scotland, with assistance from the following specialists:—Dr. Traquair, the late Professor H. Alleyne Nicholson, Professor T. Rupert Jones, Mr. J. W. Kirkby, and the late Mr. Herbert Carpenter. Recently additions have been made to the collections by Mr. D. Tait, Fossil Collector of the Survey.

In view of the preparation of the present Memoir on Central and Western Fife, the fossils from this region (Sheet 40) in the collection of the Geological Survey of Scotland have been largely re-examined under my supervision, and the fossil lists have been revised and added to. Several specialists have kindly given their valuable assistance in this work. The list of Fishes has been prepared for this volume by Dr. Traquair: that of the Ostracods by Professor T. Rupert Jones and Mr. J. W. Kirkby; that of the Lamellibranchs by Dr. J. Wheelton Hind; that of the Palæozoic Plants by Mr. R. Kidston; and that of the Post-tertiary Plants by Mr. Clement Reid.

In addition to the valuable services which have been acknowledged in the body of the present Memoir, a special debt of obligation is due to Mr. Kirkby for his help in the preparation of this Appendix. He has generously placed at our disposal copious lists of fossils collected by himself from the Carboniferous rocks. His materials are embodied in the following pages.

The various lists have been drawn up by me, with the assistance of Mr. D. Tait. They are three in number. The first is a list (A) of the localities from which fossils have been obtained; the second (B) is a general list of all the fossils which have been collected, arranged in their botanical and zoological grades, with an indication of the Stratigraphical series in which they occur; the third (C) is an enumeration of the main Stratigraphical groups, with the fossils which have been obtained from each of their subdivisions.

BEN. N. PEACH.

A. List of Localities

From which fossils have been obtained by the Geological Survey and Mr. J. W. Kirkby in Central and Western Fife and parts of the Counties of Perth, Clackmannan, and Kinross. (Sheet 40 and part of Sheet 32.)

Upper Old Red Sandstone.

I. From a wall S. side of Kinross, Loch Leven.

II. Balgeddie, by Kinnesswood.

III. Quarry at side of burn, between Wester Gospetry and Moors of Kinnesswood.

IV. Glen Burn, between Lappie and Easter Gospetry, near Burnside.

V. Glen Burn, $\frac{1}{2}$-mile above road, 2 miles north of Kinnesswood.

VI. Easter Gospetry, 3 miles N. of Kinnesswood.

VII. Easter Cash, 1 mile S.E. of Strathmiglo.

VIII. Falklandwood Farm, in old quarry W. of, 1 mile N.W. of Falkland.

IX. Quarryhaugh, N. side of R. Eden, at Pitlessie Mill.

Carboniferous.

1. Charleston Quarry, 4 miles W. of Inverkeithing.

2. Rosyth, W. of Queensferry.

3. St. David's, W. of, on shore under Seafield Cottage.

3*a*. Port Haven, $\frac{1}{2}$-mile S.W. of Aberdour.

4. Oakley Railway Cutting, $1\frac{1}{2}$ miles W. of, 6 miles W. of Dunfermline.

5. Creechy Pit, $1\frac{1}{2}$ miles N.W. of Oakley, 6 miles N.W. of Dunfermline.

5*a*. Burn at Moreland, $2\frac{1}{2}$ miles S.S.E. of Crook of Devon.

6. Scaurhill Limeworks, 3 miles S.W. of Cleish, 6 miles N.W. of Dunfermline.

7. Berrylaw Colliery, 1 mile W. of Dunfermline.

8. Berrylaw Quarries, 1 mile W. of Dunfermline.

9. Lochornie Burn, Blairadam, 2 miles S.S.E. of Cleish, shale above 1st Limestone.

9*a*. Lochornie Burn, shale above 2nd Limestone.

10. Lathalmond Quarry, 4 miles N.W. of Duufermline.
11. Roscobie Quarry, 4 miles N. of Dunfermline.
12. Dolly Limestone Quarry, near Drumfod, 4 miles N.W. of Dunfermline.
13. Linn Quarry, 4 miles N.W. of Dunfermline.
14. Cowdens Quarry, 3 miles N.W. of Dunfermline.
15. Craigluscar Quarry, 3 miles N.W. of Dunfermline.
16. Lochhead Fireclay Works, 2 miles N. of Dunfermline.
17. Craigduckie Quarry, N. of Loch Fitty.
18. Lassodie Quarry, N. of Loch Fitty.
18*a*. Touch Mains, right bank of burn below Touch Bleachfield, S.E. of Dunfermline.
19. Sunnybank Quarry, Dunfermline.
20. Blacklaw Quarry, 1 mile S.E. of Dunfermline.
21. South Fod Quarry, 2 miles E. of Dunfermline.
22. Duloch Quarry, E. of Dunfermline.
23. Woodend Quarry, Parkend Farm, S. of Fordel, 5 miles E. of Dunfermline.
24. Easter Bucklyvie Quarry, Donibristle, 5 miles E.N.E. of Dunfermline.
25. Cowdenbeath Colliery, No. 2 Pit, south side of railway, 5 miles N.E. of Dunfermline.
26. Kirkford Colliery, Cowdenbeath.
27. Lochgelly Ironworks, No. 16 Pit, E. of Ironwork, 7 miles N.E. of Dunfermline.
28. Kelty Colliery, Lindsay Pit, Lochgelly, B.B. iron.
29. Capeldrae and Rosewell Collieries, E. of Ballingry, 1 mile S.E. of Loch Leven.
30. Clattering Well, Bishop Hill, Kinnesswood.
31. Kilmundy Limestone Quarry, Burntisland.
32. Kilmundy Sandstone Quarry, Burntisland.
33. Cullalo Quarry, 2 miles N. of Aberdour.
34. Walton Quarry, 1 mile S. of Lochgelly, shale above No. 1 Limestone.
35. Little Raith, 1 mile N.W. of Auchtertool.
36. Glenniston Quarry, 4 miles N.W. of Kirkcaldy.
37. Shaws Mill Quarry, 4 miles N.W. of Kirkcaldy.
38. Leslie Limeworks.
39. Chapel Quarry, 3 miles N.W. of Kirkcaldy.
40. Potmetal Plantation, $2\frac{1}{2}$ miles N.W. of Kirkcaldy.
41. Bogie Quarry, 2 miles N.W. of Kirkcaldy.

42. Dodhead Limestone Quarry, N.E. of Burntisland.
43. Newbigging Limeworks, $1\frac{1}{2}$ miles W. of Burntisland.
44. Binnend Shale Works, Burntisland.
45. The Binn, S.E. side of, near Burntisland.
46. Grange Quarry, Burntisland.
47. Brosyhall Limestone Quarry, 1 mile N.E. of Burntisland.
48. Brosyhall Sandstone Quarry, " "
49. Pettycur, S. of Kinghorn.

50. }
50*a.*} Abden, Kinghorn—Abden Limestone, lowest limestone E. of Kinghorn. (List supplied by Mr. J. W. Kirkby.)

50*b.* Abden, Kinghorn—The same as above, limestone and shale.

50*c.* " " —White shale immediately under No. 1 Limestone.

50*d.* Abden, Kinghorn—Blue shale below No. 1 Limestone.

50*e.* " " —Productus bed (above Pecten bed) below No. 1 Limestone.

50*f.* Abden, Kinghorn—Shale below ash beds under No. 1 Limestone, Abden.

50*g.* Abden, Kinghorn—Bed above Pecton bed under No. 1 Limestone, Abden.

50*h.* Abden, Kinghorn—Pecten bed, above Myalina bed, under No. 1 Limestone, Abden.

50*i.* Abden, Kinghorn—Myalina bed, under No. 1 Limestone, Abden.

50*j.* " " —Fish bed, " " "

51. {
Abden, Kinghorn—2nd Limestone on shore E. of Kinghorn.
" " — " band, No. 3 of section.
" " — " " No. 4 "
" " —No. 2 Limestone on shore W. of Seafield Tower; shale below.
25 ft. Limestone, E. of Kinghorn. (List supplied by Mr. Kirkby.)

52. Kinghorn—3rd Limestone on shore E. of, and W. of Seafield Tower; shale above limestone.

52*a.* Kinghorn—3rd Limestone; shale below limestone.

53. Kinghorn, Seafield Tower—Shale above sandstone on which tower is built.

54. Kinghorn, E. of Seafield Tower—Top of 2nd Limestone above Seafield Tower sandstone.

55. Pathhead, on shore near—Lower Limestone (Gair). (List supplied by Mr. Kirkby.)

55*a.* Pathhead, on shore near—Lower Limestone (Gair); from shale above limestone.

55*b.* Pathhead, on shore near—Lower Limestone (Gair); from shale between limestone.

55*c*. Pathhead, on shore near—Lower Limestone (Gair); from shale below limestone.

56. Pathhead, on shore near—Upper Limestone (Levenseat), 200 yards E. of Lower Limestone.

57. Carberry Quarry, Dunnikier, 1½ miles N. of Pathhead.

58. Invertiel Quarry, W. of Linktown, Kirkcaldy.

59. Dysart.

60. Dysart Harbour.

61. Blair Point, on shore between Dysart and West Wemyss.

62. West Wemyss.

63. East Newton Pit, near East Wemyss.

64. East Wemyss.

65. Muiredge Colliery, Buckhaven, S.W. of Leven.

66. Methil, on shore W. of (red beds).

67. Pirnie Colliery, Leven—Wood coal, from bands forming roof.

68. " " —Parrot Coal.

69. Durie Colliery—Roof of Chemiss Coal.

70. Leven Colliery—Chemiss Coal horizon.

71. Durie and Leven Collieries—Roof of Eight-foot Coal.

72. Methil and Leven marine bands. (Mr. Kirkby's list.)

73. Kennoway Den.

74. Forthar Limeworks, 1½ miles S. of Kettle.

75. Pitlessie and Cults Limeworks—Shale and shaly limestone above the Hurlet Limestone.

76. Pitlessie and Cults Limeworks—From a reddish shale bed some little distance above the Hurlet Limestone.

Post-Tertiary.

Dronachy Burn, at railway cutting W. of Auchtertool.

B. General List of all the Fossils

Obtained from Central and Western Fife and Kinross, arranged in botanical and zoological grade, with their position in the Stratigraphical series, and the localities from which they have been obtained.

SPECIES.	Lower.				Upper.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
FILICALES.								
Sphenopterideæ.								
Adiantites, *Goeppert*								
,, antiquus, *Ett.* ...	×							46, 50*g*.
Calymmatotheca, *Stur.* ...	×							
,, affinis, *L. and H.*	×							31, 32, 42, 44, 46, 47, 50*j*.
,, bifida, *L. and H.*	×							46.
Cardiopteris, *Schimp.*								
,, sp.	×							50*g*.
Eremopteris, *Schimper*								
,, artemisiæfolia, *Sternb.*						×		63, 69, 70.
Rachiopteris, *Will.*								
,, duplex, *Will.* ...	×							49.
,, allied to Oldhamium, *Will.*	×							49.
Renaultia, *Zeiller*								
,, Footneri, *Marrat...*						×		61.
,, microcarpa, *Lesqx.*						×		61.
,, sp.	×							49.
Sphenopteris, *Brongt.*								
,, acutifolia, *Brongt.*						×		61.
,, crassa, *L. and H*	×							31.
,, Dunsi, *Kidston*	×							31, 46.
,, furcata, *Brongt.*						×		61.
,, (Rhodea) Hochstetteri, *Stur.*	×							46.
,, latifolia, *Brongt.*						×		61, 63.
,, Laurenti, *Andræ*						×		61.
,, (Rhodea) moravica, *Ett.* ...	×							31, 46.
,, obtusiloba, *Brongt.*						×		61, 67.
,, Schillingsi, *Andræ*						×		61.
, sp.	×		×					25, 50*g*, 65.

SPECIES.	Lower.				Upper.			Locality Number.
	Calciferous Sandstone.	Carb. Limest. Series. Lower Limestones.	Carb. Limest. Series. "Edge Coals."	Carb. Limest. Series. Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
Filicales—*continued.*								
Pecopterideæ.								
Dactylotheca, *Zeiller*								
,, plumosa, *Artis*; forma crenata, *L. and H.* ...						×		63.
Mariopteris, *Zeiller*								
,, muricata, *Schl.*...							×	61.
,, muricata, forma nervosa, *L. and H.*						×		61, 63, 64, 65, 66, 67.
Pecopteris, *Brongt.*								
,, (?) Miltoni, *Artis*							×	66.
Alethopterideæ.								
Alethopteris, *Sternb.*								
,, aquilina, *Schl.*...							×	66.
,, decurrens, *Artis*						×		64.
,, lonchitica, *Schl.*						×		61, 63, 65, 67.
Neuropterideæ.								
Neuropteris, *Brongt.*								
,, gigantea, *Sternb.*						×		67.
,, heterophylla, *Brongt.*						×		61, 63, 67.
,, rarinervis, *Bunbury*							×	66.
,, Scheuchzeri, *Hoffm.*							×	66.
Lyginodendreæ.								
Heterangium, *Corda*								
,, Grievi, *Will.* ...	×							49.
Lyginodendron, *Will.*, not *Gourlie*								
,, sp.	×							49.
Equisetales.								
Calamarieæ.								
Annularia, *Sternb.*								
,, radiata, *Brongt.* ...						×		61.
Asterocalamites, *Schimper*								
,, scrobiculatus *Sch.*	×							31, 32, 33, 42, 46, (?) 49.
Calamites (*Suckow*), *Schlotheim*								
Group I.—Calamitina, *Weiss*								
,, varians, *Sternb.* ...						×		67.
Group II.—Eucalamites, *Weiss*								
,, ramosus *Artis* = nodosus, *L. & H.*						×	×	61, 66.
Group III.—Stylocalamites, *Weiss*								

SPECIES.	LOWER.				UPPER.			Locality Number.
	Calciferous Sandstone.	Carb. Limest. Series. Lower Limestones.	Carb. Limest. Series. "Edge Coals."	Carb. Limest. Series. Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
EQUISETALES—*continued.*								
Calamites Cisti, *Brongt.* ...						×		69, 70.
,, Suckowi, *Brongt.*						×	×	61, 63, 66, 67, 68, 69, 70.
,, sp.				×		×	×	55*c*, 65, 66, 67.
Calamocladus, *Schimper*								
,, equisetiformis, *Schl.*						×	×	61, 63, 66, 68.
Palæostachya, *Weiss*								
,, pedunculata *Will.*						×		61.
SPHENOPHYLLALES.								
Sphenophyllaleæ.								
Sphenophyllum, *Brongt.*								
,, cuneifolium, *Sternb.*						×		61, 63.
,, (?) emarginatum, *Brongt.*							×	66.
,, insigne, *W. & S.*	×							49.
,, tenerrimum, *Ett.*	×							46, 47.
,, sp.						×		67.
Cheirostrobus, *Scott*								
,, pettycurensis, *Scott*	×							49.
,, sp.	×							49.
LYCOPODIALES.								
Lepidodendron, *Sternb.*								
,, ophiurus, *Brongt.*						×	×	65, 66, 68.
,, (?) rimosum, *Sternb.*							×	66.
,, veltheimianum, *Sternb.*	×							3*a*, 31, 32, 42, 43, 46, 49.
,, sp.	×		×			×		8, 25, 27, 49, 63.
Lepidophloios, *Sternb.*								
,, acerosus, *L. and H.*						×		59.
,, scoticus, *Kidston*	×							31, 42, 46, 47, 49.
Lepidophyllum, *Brongt.*								
,, lanceolatum, *L. and H.*	×						×	31, 46, 66.
,, sp.	×							3*a*.
Lepidostrobus, *Brongt.*								
,, comosus, *L. and H.*	×							31, 42, 46.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest Series. Lower Limestones.	Lower. Carb. Limest Series. "Edge Coals."	Lower. Carb. Limest Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
LYCOPODIALES—*continued.*								
Lepidostrobus variabilis, *L. and H.*	×					×	×	31, 32, 42, 46, 61, 66.
,, sp.	×					×		3*a*, 31, 43, 47, 63, 68.
Sigillaria, *Brongt.*								
Sec. I.—Clathrariæ								
,, Brardi, *Brongt.*						×		63.
Sec. II.—Leiodermariæ.								
,, camptotænia, *Wood* ...							×	66.
Sec. III.—Rhytidolepis.								
,, scutellata, *Brongt.* ...						×		63.
,, sp.						×		68.
Stigmaria, *Brongt.*								
,, ficoides, *Sternb.* ...						×		61, 68.
,, sp.	×		×	×				8, 43, 46, 49, 55*c*.
Macrospores of Lepidodendroid (?) plants						×		68.
Sporangia	×							49.
CORDAITEÆ.								
Cordaianthus, *Grand'Eury*								
,, Pitcairniæ, *L. and H.*; sp.						×		68, 69, 70.
Cordaites, *Unger*								
,, principalis, *Germar*; sp.						×		61.
,, sp.	×					×	×	42, 46, 66, 68.
Rhabdocarpus, *Göpp. & Berger*								
,, sulcatus, *Presl.*							×	66.
Trigonocarpus, *Brongt.*								
,, Parkinsoni, *Brongt.*						×		61, 67.
,, Parkinsoni, forma olivæformis, *L. & H.*							×	66.
,, sp.	×					×		3*a*, 65.
Various rootlets.								
Pinnularia, *L. and H.*								
,, capillacea *L. & H.*						×		61, 65, 67, 68.
FORAMINIFERA.								
Archæodiscus, *Brady*								
,, Karreri, *H. B. Brady*	×	×						14, 50*c*.
Climacammina, *Brady*								
,, antiqua, *H. B. Brady*	×							50*c*, 50*d*, 51.
Endothyra, *Phillips*								
,, Bowmani, *Phill.* ...	×	×		×				11, 50*f*, 51, 55*a*.

SPECIES.	LOWER.				UPPER.			Locality Number.
	Calciferous Sandstone.	Carb. Limest. Series.			Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
		Lower Limestones.	"Edge Coals."	Upper Limestones.				
FORAMINIFERA—*continued.*								
Endothyra crassa, *H. B. Brady*	×	×						50*c*, 50*d*, 51, 58.
,, globulus, *d'Eichw.*	×	×		×				50*c*, 50*d*, 51, 53, 55*a*, 55*b*.
,, macella, *W. B. Brady*	×							50*d*.
,, obliqua, *W. B. Brady*	×	×						14, 50*d*.
,, ornata, *W. B. Brady*	×							50*d*.
,, radiata, *W. B. Brady*	×			×				50*c*, 50*d*, 55*a*.
Nodosinella, *H. B. Brady*								
,, concinna, *H. B. Brady*		×						14.
Saccammina, *Sars.*								
,, sp.		×						19.
Stacheia, *H. B. Brady*								
,, congesta, *H. B. Brady*	×	×						50*c*, 53.
,, fusiformis, *H. B. Brady*		×						14.
,, polytrematoides, *H. B. Brady*	×	×						1, 36, 50*f*.
,, pupoides, *H. B. Brady*	×	×						11, 14, 50, 53, 58.
,, sp.				×				55*a*.
Textularia, *Defrance*								
,, eximia, *d'Eichw.*	×							51.
,, gibbosa *d'Orb.* ...	×							50*d*.
Trochammina, *Parker & Jones*								
,, anceps, *H. B. Brady*		×						53.
,, incerta, *d'Orb.*	×	×		×				1, 11, 14, 19, 36, 50*d*, 53, 55*a*, 55*b*, 58.
Valvulina, *d'Orbigny*								
,, decurrens, *Brady*...	×	×		×				14, 50*c*, 50*d*, 50*f*, 55*a*, 55*b*.
,, palæotrochus, *H. B. Brady*	×	×						1, 11, 14, 19, 50*c*, 50*d*, 50*f*, 51, 58.
,, palæotrochus, var. compressa, *H. B. Brady*		×						1, 11, 19, 53.
,, plicata, *H. B. Brady*	×							50*c*, 50*d*.
,, rudis (?), *H. B. Brady*	(?)							50*d*.
,, Youngi, *H. B. Brady*	×	×						14, 50*c*, 50*c*, 58.
,, ,, var. contraria, *H.B.Brady*		×						11 14.
Onion-like bodies (Foraminifera ?)	×	×						50*d* 58.
PORIFERA.								
Acanthospongia, *M'Coy*								
,, Smithi, *Young*		×						1, 11.
Ascodictyon, *Nic. and Eth.*								
,, radians, *N. and E.*		×						11, 23.

SERIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
PORIFERA—*continued.*								
Hyalostelia, *Zittel*								
,, (Hyalonema) parallela, *M'Coy* ...		×		×				1, 11, 40, 41, 55*a*, 58, 75.
Peronidella, *Zittel*								
,, sparsa, *Hinde* ...		×						23.
Sponge borings in Chonetes and Crinoids		×						10, 11, 22.
HYDROZOA.								
Palæocoryne, *Dunc. and Jenk.*								
,, sp.		×		×				1, 11, 17, 40, 55*a*, 55*b*.
ACTINOZOA.								
Amplexus, *Sowerby*								
,, coralloides, *Sow.* ...		×						52.
,, ibicinus, *Fisch.* ...		×						22.
,, spinosus, *de Kon.*...		×						1, (?)11, 13, (?)20, 22.
,, sp.		×						11, 37, 41.
Aspidophyllum, *Thompson*								
,, sp.		×						41.
Aulopora, *Goldfuss*								
,, campanulata, *M'Coy*		×						22.
,, sp.		×						22.
Chætetes, *Fischer*								
,, tumidus, *Phill.* ...		×		×				11, 14, 29, 54, 74.
,, sp.		×						1, 10, 17, 18, 22, 52, 53, 58.
Cladoconus, *M'Coy*								
,, Michelini, *Edw. and Haime* ...		×						22.
Clisiophyllum, *Dana*								
,, coniseptum, *Keyser.*		×						41.
,, turbinatum, *M'Coy*		×						1, 39, 58.
,, sp.	×	×						11, 22, 50*a*, 51, 52, 58.
Cyathaxonia, *Michelin*								
,, cornu, *Mich.* ...		×						10, 14, 21.
Cyathophyllum, *Goldfuss*								
,, (Campophyllum) paracida, *M'Coy*		×						41.
Cyclophyllum, *Duncan and Thompson*								
,, (Aulophyllum) fungites, *Flem.*	×	×						1, 34, 41, 51.
Dibunophyllum, *Thompson*								
,, sp.		×						41.

SPECIES.	Lower.				Upper.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
ACTINOZOA—*continued.*								
Favosites, *Lamarck*								
,, parasitica, *Phill.* ...		×						11, 22, (?) 58.
Heterophyllia, *M'Coy*								
,, granulata, *Duncan*		×						1.
,, Lyelli, *Duncan*		×						1.
Lithostrotion, *Lhwyd.*								
,, irregulare, *Phill.*	×	×						51, 52.
,, junceum, *Flem.*		×						39, 41.
,, sp.		×						1, 9.
Lonsdaleia, *M. Edw.*								
,, sp....		×						1.
Lophophyllum, *Edw. and Haime*								
,, eruca, *M'Coy*		×						22.
,, parvulum, *Thom. & Nich.*		×						1, (?) 21.
,, sp., No. 2* ...		×						1.
,, sp., No. 4* ...		×						1.
,, sp.		×						41, 58.
Michelinia, *de Kon.*								
,, near megastoma, *Phill.*		×						22.
Palæacis, *Edw. and Haime*								
,, compressa, *Meek and Worth.*		×						10, 13, 23.
,, cyclostoma, *Phill.*...		×						1, 10, 11, 13, 14, 19, 20, 21, 22, 23, 36, 52.
Syringopora, *Goldfuss*								
,, sp.		×						1.
Zaphrentis, *Rafinesque*								
,, near centralis, *E. and H.*		×						22.
,, cliffordiana, *E. & H.*		×						1, 10, (?) 11, 13, 21.
,, Enniskilleni, *M. Edw.*		×						1, 11, 22, 34, 52, 52*a*.
,, Griffithsi, *M. Edw.*		×						11.
,, Phillipsi, *M. Edw.*				×				73.
,, sp.	×	×						9*a*, 41, 50*a*, 58.
Corals indet.		×		×				55*a*, 74, 75.
ECHINODERMATA.								
Crinoidea.								
Actinocrinus, *Miller*								
,, sp.						(?)		72.
Cupressocrinus, *Goldfuss*								
,, impressus, *M'Coy* (=Poteriocrinus M'Coyanus, *de Kon. and Le Hon.*) ...		×						11.

* M.S. *Eth., jr.*, in Geological Survey List Books.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
ECHINODERMATA—*cont'd.*								
Hydreionocrinus, *de Kon.*								
,, globularis, *de Kon.*	×	×						11, (?) 22, 51.
,, sp.		(?)						(?) 1, (?) 14, 58.
Platycrinus, *Miller*								
,, near arenosus ...		×						11.
,, trigintidactylus, *Aust.*		×						1, 11, 14.
,, sp.		×		×				38, 52, 58, 73.
Poteriocrinus, *Miller*								
,, crassus, *Miller*		×		×				10, (?) 11, 22, 29, 34, 58.
,, near crassus, *Miller*		×						22.
,, nuciformis, *M'Coy*		×						21, 22.
,, tenuis, *Miller*...		×						1.
,, sp. near ventricosus				×				57.
,, new sp. allied to P. nuciformis		×						22.
,, sp.				×				(?) 14, 56, (?) 72, 73.
Crinoid ossicles...	×	×		×		×		4, 6, 10, 13, 17, 34, 36, 39, 40, 41, 50*c* 50*d*, 51, 53, 55*a* 55*b*, 57, 72, 75, 76
Blastoidea.								
Astrocrinites, *Austin*								
,, Benniei, *R. Eth., jr.*		×						11, 58.
Echinoidea.								
Archæocidaris, *M'Coy*								
,, Urei, *Flem.* ...		×						1, 11, 75.
,, sp.	×	×		×				10, 17, 22, 23, 34, 36, 41, 50*c*, 50*d*, 51, 53, 55, 55*a*, 55*b*, 58.
Holothuridea.								
Achistrum, *R. Eth., jr.*								
,, Nicolsoni, *R. Eth., jr.*		×						23.
Cheirodota, *Eschscholtz*								
,, Traquairi, *R. Eth. jr.*		×						23.
Holothurian remains		×						10, 11, 19, 36.
ANNELIDA.								
Ortonia, *Nicholson*								
,, carbonaria, *Young* ...		×		×				55*a*, 58.
,, sp.		(?)		×				53, 55*b*.
Serpulites, *M'Leay*								
,, carbonarius, *M'Coy*	×	×						10, 11, 13, (?) 22, 51 52*a*, 56, 58.

SPECIES.	LOWER. Calciferous Sandstone.	LOWER. Carb. Limest. Series. Lower Limestones.	LOWER. Carb. Limest. Series. "Edge Coals."	LOWER. Carb. Limest. Series. Upper Limestones.	UPPER. Millstone Grit.	UPPER. Lower Coal-measures.	UPPER. Mid. or Red Coal-measures.	Locality Number.
ANNELIDA—*continued.*								
Serpulites ? membranaceus, *M'Coy*		×						22.
,, sp.	×	×		×				1, 3, 55*c*.
Spiroglyphus, *M'Coy*								
,, sp.		×						22.
Spirorbis, *Lamarck*								
,, ambiguus, *Flem.* ...		×						1, 11, 75.
,, caperatus, *M'Coy* ...	×	×						1, 50*d*, 51, 58, 75.
,, globosus, *M'Coy* ...		×						22.
,, (carbonarius, *Murch.*) = pusillus, *Martin*	×	×	×			×		23, 28, 43, 65, 68, 71.
,, spinosus, *de Kon.* ...		×						11, 17, 34.
,, sp.		×		×				14, 53, 55*a*, 55*c*.
Vermilia, *Lamarck*								
,, sp.		×						22.
Various tracks						×		68.
ARTHROPODA.								
Ostracoda.								
Argillœcia, *Sars*								
,, æqualis, *Jones and Kirkby*	×							3*a*.
Bairdia, *M'Coy*								
,, ampla, *Reuss*	×	×						50*d*, 53, 58, 75.
,, brevis, *J. and K.* ...	×	×						1, 50*c*, 50*d*, 50*g*, 53, 58, 75.
,, curta, *M'Coy* ...	×	×						1, 50*f*, 58, 75.
,, ,, var.	×	×						50*c*, 50*g*, 58.
,, grandis, *J. and K.* ...		×						58.
,, Hisingeri, *Münster* ...	×	×						1, 19, 50*c*, 50*d*, 50*f*, 50*g*, 51, 58, 75.
,, plebeia, *Reuss* ...	×	×		×				1, 34, 50*c*, 50*d*, 50*f*, 50*g*, 51, 53, 55*a*, 58.
,, ,, var.		×						1.
,, subcylindrica, *Münster*	×							50*d*.
,, subelongata, *J. and K.*	×	×		×				1, 50*c*, 50*g*, 51, 55*a*, 55*b*, 58, 75.
,, submucronata, *J. & K.*	×	×		×				1, 19, 23, 50*c*, 50*d*, 50*g*, 51, 55*a*, 58.
,, ,, var. ...		×						19.
,, sp.		×		×				26, 34, 55*a*.
Beyrichia, *M'Coy*								
,, bradyana, *J. and K.*				×				26.
,, fastigiata, *J. & K.*	×							3*a*.
,, tuberculospinosa, *J. and K.* ...				×				29.
,, radiata, *J. and K.*		×		×				19, 20, 23, 29, 73.
,, varicosa, *J. and K.*		×						36.
,, sp.	×			×				19, 29, 36, 50*f*, (?) 55*a*.
Beyrichiella, *J. and K.*								
,, ventricornis, *J. & K.*		×						1, 14, 58.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
Arthropoda—*continued.*								
Beyrichiopsis, *J. and K.*								
,, fimbriata, *J. & K.*	×							3*a*.
,, ,, var....	×							3*a*.
Bythocypris, *Brady*								
,, cornigera, *J. and K.*	×	×						1, 14, 19, 36, 50*d*.
,, (Cythere) cuneola, *J. and K.*	×	×		×				23, 26, 29, 50*c*, 50*g*, 73.
,, near cuneola								
,, cuneola		×		×				36, 50*f*, 55*a*.
,, phillipsiana, var. carbonica, *J. and K.* ...				×				26, 29, 73.
Bythocythere, *Sars*								
,, ? youngiana, *J. and K.*				(?)				26.
Carbonia, *Jones*								
,, fabulina, *J. and K.*			×			×	×	27, 66, 68, 71.
,, rankiniana, *J. and K.*						×	×	66, 68.
,, secans, *J. and K.* ...							×	66.
Cypridina, *M. Edwards*								
,, sp.		×						20.
Cythere, *Müller*								
,, ? superba, *J. and K.*	×							3*a*.
,, sp.		×						14, 19, 23, 53.
Cytherella, *Jones*								
,, attenuata, *J. & K.*	×							3*a*.
,, Benniei, *J. and K.*				×				26, 73.
,, extuberata, *J. & K.*	×							3*a*.
,, recta, *J., K., and B.*				×				29, 73.
,, sp....		×		×				1, 14, 26.
Kirkbya, *Jones*								
,, costata, *M'Coy* ...		×						75.
,, obsoleta, *J. and K.*		×						53.
,, permiana, *Jones* ...	×	×		×				14, 29, 36, 50*d*, 58, 75.
,, ,, var. ...				×				73.
,, plicata, *J. and K.*...	×							3*a*.
,, rigida, *J. and K.* ...				×				29.
,, scotica, *J. and K.* ...				×				26.
,, spinosa, *J. and K.*...	×			×				50*d*, 55*a*.
,, spiralis, *J. and K.*...	×							5*a*.
,, striolata, ? *d'Eich* ...		×						53.
,, umbonata, *d'Eichw.*		×						1, 14.
,, Urei, *Jones*	×	×		×				19, 23, 36, 50*d*, 53, 58, 75.
,, sp.				×				29, (?) 55*a*, 73.
Leperditia, *Rouält.*								
,, acuta, *J. and K.*...				×				29.
,, armstrongiana, *J. and K.*		×						75.
,, ? inornata, *M'Coy*				×				29.
,, Okeni, *Münst.* ...	×	×		×				5*a*, 19, 20, 23, 29, 34, 36, 38, 43, 50*a*, 50*d*, 50*f*, 53, 73, 75.

SPECIES.	LOWER. Calciferous Sandstone.	LOWER. Carb. Limest. Series. Lower Limestones.	LOWER. Carb. Limest. Series. "Edge Coals."	LOWER. Carb. Limest. Series. Upper Limestones.	UPPER. Millstone Grit.	UPPER. Lower Coal-measures.	UPPER. Mid. or Red Coal-measures.	Locality Number.
ARTHROPODA—*continued.*								
Leperditia Okeni, var. acuta, *J. and K.*		×						58.
,, ,, vars. ...				×				5*a*, 29, 36.
,, scotoburdigalensis, *Hibbert*	×							43, 46.
,, suborbiculata, *Münst.*	×							43, (?) 50*f*.
,, sp.								
Ulrichia, *Jones*								
,, (Beyrichia) bituberculata, *M'Coy* ...				×				26.
Youngia, *J. and K.*								
,, rectidorsalis, *J. & K.*				(?)				(?) 73.
Ostracoda indet.			×					27, 28.
Phyllopoda.								
Leaia, *Jones*								
,, Leidyi, *Lea*						×	×	66.
Phyllocarida.								
Dithyrocaris, *Scouler*								
,, sp.		×		(?)				9*a*, 12, 14, (?) 55*a*.
Trilobita.								
Phillipsia, *Portlock*								
,, Eichwaldi, *Fisch.*...		×						30, 75.
,, ,, var. mucronata, *M'Coy*		×		×				10, 11, 38, 41, 57, (?) 58, 73, 75.
,, sp.		×		×				10, 17, 40 55*a*.
Merostomata.								
Belinurus, *König*								
,, trilobitoides, *Buckl.*							×	66.
Prestwichia, *H. Woodward*								
,, anthrax, *H. Woodward*							×	66.
Eurypterus, *Dekay*								
,, mammatus, *Salter*							×	66.
Arachnida.								
Eoscorpius, *Meek and Worthen**								
,, anglicus, *H. Woodward*						×		61.
,, tuberculatus, *B. N. Peach*						×		61.
,, sp.	×							50*f*.
Myriapoda.								
Myriapod sp.						×		61.

* Mr. Bennie, by means of washing, has found that fragments of scorpion skin are plentiful in coaly seams throughout all the horizons of the Carboniferous system in Scotland.

SPECIES.	Lower.				Upper.			Locality Number.
	Calciferous Sandstone.	Carb. Limest. Series.			Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
		Lower Limestones.	"Edge Coals."	Upper Limestones.				
Polyzoa.								
Calamopora, *Goldfuss*								
,, (Carinella) sp. ...		×						54.
Ceriopora, *Goldfuss*								
,, interporosa, *Phill.*		×						53.
,, similis, *Portl.* ...				×				73.
,, sp.		×						38, 74, 75.
Diastopora, *Lamouroux*								
,, megastoma, *M'Coy*		×		×				1, 10, 11, 53, 73.
,, sp.		×		×				11, 20, 22, 55*a*, 57, 58.
Fenestella, *Lonsdale*								
,, Morrisi, *M'Coy* ...		×						75.
,, multiporata, *M'Coy*		×						38.
,, plebeia, *M'Coy* ...		×						30, 40, 41, 74, 75.
,, undulata, *Phill.*...		×						75.
,, sp.	×	×		×				1, 10, 11, 14, 40, 50*e*, 52, 52*a*, 53, 54, 55*a*, 55*b*, 58.
Glauconome, *Goldfuss*								
,, elegantula, *R. Ether.*		×						54.
,, pulcherrima, *M'Coy*		×						30.
,, sp.		×		×				1, 10, 11, 14, 40, 41 53, 55*a*, 55*b*, 58 74, 75.
Goniocladia, *R. Ether., jun.*								
,, cellulifera, *R. Ether., jun.*		×		×				14, 55*a*.
,, cellulifera, or nov. sp.		×						14.
,, sp.		×						14, 54.
Hippothoa, *Lamouroux*								
,, Hincksi, m.s., *R. Ether., jun.*		×						11.
Hyphasmopora, *R. Ether., jun.*								
,, (Vincularia) Benniei, *R. Ether., jun.*		×						22.
,, (Rhombopora ?) Buski, *R. Ether., jun.*	×	×						50*c*, 50*d*, 53.
Polypora, *M'Coy*								
,, tuberculata, *Prout*		×						41, 75.
,, sp.		×						58.
Rhabdomeson, *Young*								
,, gracile, *Phill.*		×						53, 54.
,, rhombiferum, *Phill.*		×						11, 54.
,, sp.	×	×						1, 10, 50*c*, 50*d*, 58.
Rhombopora, Meek. (*See* Hyphasmopora).								
,, sp.	×							50*d*.

SPECIES.	LOWER.				UPPER.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
POLYZOA—*continued.*								
Sulcoretepora, *D'Orbigny*								
,, parallela, *Phill.*	×	×						50*c*, 50*d*, 58.
,, sp.	×	×						1, 11, 38, 41, 51, 54, 58.
Thamniscus, *King*								
,, pustulosus, *R. Ether., jun.*		(?)		(?)				(?) 55*a*, 58.
Polyzoa indet.		×						6.
BRACHIOPODA.								
Athyris, *M'Coy*								
,, ambigua, *Sow.* ...	×	×		×				1, 11, 29, 30, 34, 41, 50*e*, 53, 55*c*, 57, 74, 75.
,, Roysii, *Léveillé* ...		×		×				1, 11, 14, 22, 29, 34, 38, 39, 41, 58, 73, 74, 75.
,, sp.								18*a*.
Chonetes, *Fischer*								
,, buchiana, *de Kon.*		×						1, 74.
,, comoides, *Sow.* ...		×						1.
,, laguessiana, *de Kon.*	×	×		×				1, 10, 11, 20, 23, 29, 34, 38, 40, 51, 55, 55*c*, 56, 57, 58, 74, 75.
,, polita, *M'Coy* ...	(?)	×						34, 38, 40, 50*d*, 75.
,, sp.		×						1, 34.
Crania, *Retzius*								
,, quadrata, *M'Coy* ...		×						34, 53.
,, sp.	×							51.
Discina, *Lamarck*								
,, nitida, *Phill.* ...	×	×		×		×		10, 11, 13, 24, 29, 34, 50*a*, 50*b*, 51, 55, 55*a*, 55*c*, 56, 72, 74, 75.
,, sp.		×						39, 40.
Lingula, *Bruguière*								
,, mytiloides, *Sow.* ...	×	×		×		×		3*a*, 10, 13, 20, 40, 50*a*, 50*b*, (?) 50*e*, 55, 55*a*, 55*c*, 56, 58, 72, 75.
,, squamiformis, *Phill.*	×	×	×			×		3*a*, 10, 11, 20, 24, 50*g*, 50*h*, 50*j*, 51, 72.
,, ,, var.			×					7.
,, sp.	×	×		×				1, 14, 29, 50*b*, 50*g*, 51.
Orthis, *Dalman*								
,, Michelini, *Léveillé* ...	×	×		×				1, 11, 14, (?) 21, 41, 50*e*, 57, 58.
esupinata, *Martin* ...	×	×		×				1, 13, 29, 34, 35, 41, 50*a*, 51, 55, 55*a*, 55*c*, 74, 75.

SPECIES.	LOWER. Calciferous Sandstone.	LOWER. Carb. Limest. Series. Lower Limestones.	LOWER. Carb. Limest. Series. "Edge Coals."	LOWER. Carb. Limest. Series. Upper Limestones.	UPPER. Millstone Grit.	UPPER. Lower Coal-measures.	UPPER. Mid. or Red Coal-measures.	Locality Number.
BRACHIOPODA—*cont'd.*								
Orthis, sp.	×	×		×				24, 50*d*, 51, 55*a*, 55*c*.
Productus, *Sowerby*								
,, aculeatus, *Martin*		×						1, 11, 41, 53, 58, 74.
,, complectens, *R. Ether., jun.*	×	×		×				11, (?) 18, 51, 55*a*, (?) 58.
,, costatus, *Sowerby*...	(?)	×		×				1, 13, 18*a*, (?) 41, 51, 55.
,, near costatus ...		×						
,, elegans, *M'Coy* ...		×						40.
,, fimbriatus, *Sow.* ...		×						41, (?) 58.
,, giganteus, *Martin*		×		×				41, 55*b*, 58.
,, latissimus, *Sow.* ...		×		×				41, 55, 75.
,, longispinus, *Sow.*...	×	×		×				10, 11, 12, 13, 14, 18*a*, 20, 21, 22, 23, 24, 29, 30, 34, 35, 37, 38, 40, 41, 50*a*, 50*b*, 50*c*, 51, (?) 52, 52*a*, 53, 54, 55, 55*a*, 58, 74, 75.
,, near margaritaceus, *Phill.*		×						1.
,, mesolobus, *Phill.*...	×	×						1, 50*c*.
,, punctatus, *Martin*	×	×						1, 6, 11, 22, 30, 40, 41, 51, 52, 58, 74, 75.
,, pustulosus, *Phill.*...		×						1, 40, 41.
,, scabriculus, *Martin*	×	×		×				1, 11, 29, 30, 40, 50*b*, (?) 55*c*, (?) 58, 75.
,, semireticulatus, *Martin*	×	×						1, 11, 13, 18*a*, 22, 34, 35, 38, 40, 41, 50*a*, 50*b*, 50*c*, 51, 52, 58, 73, 74, 75.
,, ,, var. concinnus, *Sow.*				×				73.
,, ,, ,, Martini, *Sow.*		×				×		40, 52*a*, 72.
,, sinuatus, *de Kon.*				×				56.
,, youngianus, *Dav* ...		×						35, 40, 41, 58, 75.
,, sp.	×	×		×				6, 15, 21, 50*d*, 50*g*, 55*b*, 57.
Retzia, *King*								
,, radialis, *Phill.* ...		×						14, 41.
Rhynchonella, *Fischer*								
,, pleurodon, *Phill.*	×	×		×				11, 14, 18*a*, 29, 38, 41, 50*a*, 50*b*.
,, sp.	×	×		×				21, 50*c*, 55*a*, 55*c*.
Spirifera, *Sowerby*								
,, (?) carlukensis, *Dav.*		×						22, 41.
,, duplicicosta, *Phill.*...	×	×						1, 40, 41, 51, 52*a*.
,, near crassa, *de Kon.*		(?)						41.
,, glabra, *Martin* ...		×						1, (?) 11, 22, 41, 58.
,, lineata, *Martin* ...		×						1, 11, 41, 53, 58, 74, 75.

SPECIES.	LOWER. Calciferous Sandstone.	LOWER. Carb. Limest. Series. Lower Limestones.	LOWER. Carb. Limest. Series. "Edge Coals."	LOWER. Carb. Limest. Series. Upper Limestones.	UPPER. Millstone Grit.	UPPER. Lower Coal-measures.	UPPER. Mid. or Red Coal-measures.	Locality Number.
BRACHIOPODA—*cont'd.*								
Spirifera lineata, var.		×						22.
,, ovalis, *Phill.* ...		×		(?)				(?) 1, (?) 29, 38, 40, 41, 75.
,, pinguis, *Sow.* ...				(?)				29.
,, trigonalis, *Martin* ...		×		×				6, 11, 15, 22, 29, 38, 40, 41, 52*a*, 54, 74, 75.
,, ,, var. bisulcata, *Sow.*		×		×				1, 11, 22, 55, 73.
,, ,, var. ...		×		×				29, 53, 55*a*, 55*c*, 58.
,, Urei, *Flem.* ...	×	×		×				10, 11, 12, 13, 14, 21, 22, 23, 24, 38, 50*a*, 55*b*, 56, 57.
,, sp.	×	×						18*a*, 34, 39, 50*c*, 50*e*, 50*f*, 51.
Spiriferina, *D'Orbigny*								
,, cristata, *Schloth.*...	×	×						1, 11, 14, 38, 40, 41, 51, 58, 74, 75.
,, ,, var. octoplicata, *Sow.*		×		×				(?) 6, 14, 41, 55.
,, sp.		×						10.
Streptorhynchus, *King*								
,, (Orthotetes) crenistria, *Phill.*	×	×		×				1, 5, 14, 18*a*, 29, 30, 34, 38, 40, 41, 50*e*, 51, 55, 55*a*, 55*c*, 58, 73, 74, 75.
,, ,, var.		×						58.
,, sp.	×							22, 50*d*.
Strophomena, *Rafinesque*								
,, analoga, var. distorta, *Sow.*		×						14.
Terebratula, *Llhwyd*								
,, hastata, *Sow.* ...		×						38, 41 75.
,, sacculus, *Martin*		×						5, 10, 41.
,, ,, var. ...		×		×				22.
,, vesicularis, *De Kon.*		×						41.
,, sp.		×						11, 58.
LAMELLIBRANCHIATA.								
Monomyaria.								
Avicula, *Klein*								
,, sp.	×							50*b*.
Aviculopecten, *M'Coy*								
,, arenosus, *Phill.*		×		(?)				(?) 55, 76.
,, coelatus, *M'Coy*	×	×						1, 11, 40, 50*b*.
,, concavus, *M'Coy*		×						30, 40.
,, dissimilis, *Phill.*	×	×						1, 11, 40, 50*b*, 58.
,, docens, *M'Coy*		×						40, 58.
,, fimbriatus, *Phill.*		×						75.
,, (?) granosus, *Sow.*	×	×						24, 51.

SPECIES.	LOWER.				UPPER.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
LAMELLIBRANCHIATA—*cont'd.*								
Aviculopecten (Pecten) hemisphæricus, *Phil.*	×							51.
,, interstitialis, *Phill.*	×	×						38, 50*b*.
,, ornatus, *R. Eth., jun.*	×	×		×				(?) 9*a*, 40, 50*b*, 50*g*, 50*h*, 50*i*, 51, 55*c*, 58.
,, planoradiatus, *M'Coy*		(?)						58.
,, (Entolium) Sowerbyi, *M'Coy*	×	×						15, 34, 50*e*, 58.
,, subconoides, *R. Eth., jun.*	×							50*b*, 50*e*.
,, sp.	×	×		×				18, 30, 38, 41, 50*j*, 51, 53, 55*a*, 56, 58, 75, 76.
Pecten, *Müller*								
,, sp.		×						18*a*.
Pinna, *Linnæus*								
,, flabelliformis, *Martin*...		×						11, 40, 41, 58.
Posidonomya, *Bronn*								
,, corrugata, *R. Eth., jun.*		×						11.
,, sp.		×						20.
Pterinea, *Goldfuss*								
,, sp.	(?)	(?)						(?) 40, 50*b*.
Pteronites, *M'Coy*								
,, persulcatus, *M'Coy*	×			×				50*e*, 50*g*, 50*h*, 50*i*, 55*c*.
,, sulcatus, *M'Coy* ...	×			×				50*b*, 55*c*.
,, sp.	×	(?)						3, (?) 40, 51, 58.
Dimyaria.								
Allorisma, *King*								
,, *maxima.* (*See* Sanguinolites)								
Anthracomya, *Salter*								
,, lævis, var. scotica, *R. Eth., jun.*	×							48, 49.
,, modiolaris, *Sow.*							(?)	66.
* ,, Phillipsi, *Will.*		×	×					11, 27, 28.
,, Wardi, *Eth.* ...						×	×	66, 71.
,, Williamsoni, *Brown* ...						×		62.
,, sp.						×		62, 68.
Anthracoptera. (*See* Naiadites)								
Carbonicola, *M'Coy*								
,, acuta, *Sow.* ...						×		62, 71.
,, aquilina, *Sow.* ...						×		71.
,, turgida, *Brown*...						×		62.
Cardiomorpha, *de Kon.*								
,, oblonga, *Sow.*				×				55.
,, sp.				×				55*c*, 73.

* Dr. Wheelton Hind remarks that the slab containing these fossils is like the Bassey mine ironstone of North Staffordshire Coal-field, and is filled with the same compressed shell.

SPECIES.	LOWER.				UPPER.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
LAMELLIBRANCHIATA—*cont'd.*								
Conocardium, *Bronn.*								
,, aliforme, *Sow.*		×						40, 41, 58, 75.
,, sp.		×		×				58, 73.
Ctenodonta, *Salter*								
,, sinuosa, *de Kon.*		×		×				20, 55*a*, 55*c*.
Cypricardella, *Hall*								
,, (?) (Cypricardia) acuticarinata, *Arms.* ...		(?)						(?) 11.
,, concentrica, *Hind*		×						40, 75.
,, parallela, *Phill.*		×						11, 21, 22, 58.
,, rectangularis, *M'Coy*		×		×				(?) 40, 41, 73.
,, sp.		×						11.
Edmondia, *de Kon.*								
,, Josepha, *de Kon.*	×	×		×				11, 50*b*, 55*c*, 56.
,, Lyelli, *Hind* ...	×			×				50*b*, 55*c*.
,, rudis, *M'Coy* ...	(?)	×		×				38, (?) 50*e*, 50*g*, 55, 55*a*, 55*c*, 75.
,, scalaris, *M'Coy* ...		×						11, (?) 40.
,, sulcata, *Phill.* ...		×						41, 58, 75.
,, unioniformis, *Phill.*	(?)	×		×				1 (?), 11, 24, 38, 40, (?) 50*e*, 55, 55*c*, (?) 56.
,, sp.	×	×						40, 50*a* 58.
Lithodomus, *Cuvier*								
,, carbonarius, *Hind*	×							50*b*, 50*j*.
,, lingualis, *Phill.*		×						40.
,, lithodomoides, *R. Eth., jr,* ...		×						40.
Modiola, *Lamarck*								
,, elongata, *Phill.* ...		×						75.
,, sp.	×	×						5*a*, 41, 50*b*.
Myalina, *de Kon.*								
,, Flemingi, *M'Coy,* ...	×			×				50*b*, (?) 55*c*.
,, sublamellosa, *R. Eth., jun.*	×							50*b*, 50*g*, 50*h*.
,, sp.	×	×		×				3, 11, 50*h*, 51, 55*c*, 58.
Mytilomorpha								
,, rhombea, *Phill.*		×						58.
Naiadites, *Dawson*								
,, (Anthracoptera) carinata, *Sow.* ...						×		71.
,, (Myalina) crassa, *Flem.*	×	×						50*i*, 75, 76.
,, modiolaris, *Sow.* ...						×		62.
,, obesa, *R. Eth, jun.*	×							2.
,, quadrata, *Sow.* ...						×		62.
,, sp.	×							3, 50*i*.
Nucula, *Lamarck*								
,, acuta, *Sow.*		×						(?) 10, 38.
,, near acuta, *Sow.* ...		×						10.

SPECIES.	Lower.				Upper.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
LAMELLIBRANCHIATA—*cont'd.*								
Nucula gibbosa, *Flem.* ...	×	×		×				1, 9*a*, 10, 13, 19, 20, 21, 22, 23, 29, 38, 50*e*, 55, 55*c*, 56, 57, 73.
,, lævirostrum, *Portl.* ...		×		×				(?) 10, 20, 22, 24, 73.
,, lineata, *Phill.* = N. scotica		×						22, 23.
,, luciniformis, *Phill.* ...		×						1, 20.
,, sp.		×						36, 39, 58.
Nuculana, *Link*								
,, attenuata, *Flem.* ...	×	×		×				1, 10, 11, 12, 13, 14, 19, 20, 21, 22, 23, 24, 29, 38, 40, 50, (?) 51, 55, 55*a*, 55*c*, 56, 73.
,, brevirostrum, *Phill.*		×						13, 20, 22, 23.
,, (intermedia, *R. Eth., jun.*) = lævistriata, *Meek and Worthen*		×		×				5, 10, 11, 13, 29, 55, 55*c*.
,, sp.	×							51, 55.
Parallelodon, *Mor. & Lyc.*								
,, (Arca) bistriatus, *Portl.*		(?)						(?) 40.
,, ,, divisus, *M'Coy*	×	×						50*b*, 58.
,, ,, semicostatus, *M'Coy*		×		×				22, 38, 73, 75.
,, ,, sp. ...	×	×		×				38, 40, 50*d*, 52*a*, 73, 75.
Protoschizodus, *de Kon.*								
,, axiniformis, *Portl.*								
,, =P. carbonarius, *Portl.*	×	×		×				24, 38, 40, 50*b*, 55, 55*c*, 73, 75.
,, obliquus, *M'Coy*		×		×				24, 55*e*.
,, sp.	×							(?) 3.
Sanguinolites, *M'Coy*								
,, abdenensis, *R. Eth., jun.*	×							3*a*, 50*b*, 50*g*, 50*h*, 50*i*, 50*j*.
,, angustatus, *Phill.*		×						24.
,, (Allorisma) maximus, *Portl.*...	×							50*b*.
,, (Leptodomus) costellatus, *M'Coy*		×						1, 11, 12, 13, 14, 20, 23, 24, 75.
,, iridinoides, *M'Coy* = S. plicatus, *Portl.*		×						74, 75.
,, oblongus, *Portl.*		(?)						(?) 40.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
Lamellibranchiata—*cont'd.*								
Sanguinolites striato-lamellosus, *de Kon.*	×	×		×				38, 50*b*, 55*c*.
,, striatus, *Goldf.*		×						75.
,, tricostatus, *Portl.*		×						18*a*, 40, 75.
,, visètensis (?), *de Kon.*		×						11.
,, sp.	×	×				×		3, 11, 58, 72.
Schizodus, *King*								
,, deltoideus, *Portl.* (=Protoschizodus axiniformis, *Portl.*)	×	×		×				24, 38, 40, 50*b*, 55, 55*c*, 73, 75.
,, sp.	×	×		(?)				5, 40, 51, 55*c*.
Sedgwickia, *M'Coy*								
,, (?) gigantea, *M'Coy*		(?)						58.
,, suborbicularis, *M'Coy*	×	×						40, 50*b*, 51, 52*a*, 58.
Solenomya, *Lamarck*								
,, excisa, *de Kon.* ...		×						11.
,, primæva, *Phill.* ...	×	×						11, 50*b*.
,, sp.	×							39, 50*b*.
Solenopsis, *M'Coy*								
,, minor, *M'Coy* ...				×				55*a*.
,, sp.				(?)				(?) 55, 55c.
Gasteropoda.								
Aclisina, *de Kon.*								
,, elongata, *Flem.* ...		×						75.
,, gracilis, *Salt.* ...		×						40.
,, (Murchisonia) striatula, *de Kon.*	×	×		×		×		1, 50, (?) 53, 55, 55*a*, 58, 72.
Acroculia, *Phill.* (= Platyceras, *Con.* = Capulus, *Mont.*)								
,, neritoides, *Phill.* ...		×		×				41, 73.
,, vetusta, *Sow.* ...		×						75.
,, sp.		×		×				29, 58.
Bellerophon, *Montfort*								
,, decussatus, *Flem.*	×	×		×		×		3, 5, 6, 10, 11, 13, 18*a*, 20, 21, 23, 36, 40, 50*c*, 51, 55, 55*a*, 55*c*, 72, 73, 75.
,, Dumonti, *F. d'Orb.*	×							50*a*.
,, leveilleanus, *de Kon.*				×				55, 73.
,, Oldhami, *Portl.* ...		×						1, 6, 13, 15, 20, 23.
,, striatus, *Flem.* ...	×	×		×				13, 50*b*, 55c, 75.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
GASTEROPODA—*continued.*								
Bellerophon Urei, *Flem.* ...	×	×		×		×		6, 10, 15, 20, 21, 22, 23, 24, 29, 38, 40, 50*b*, 50*g*, 55, 55*a*, 55*c*, 72, 73, 75.
,, sp.	×							14, 41, 51.
Dentalium, *Linnæus*								
,, ingens, *de Kon.* ...		×						10, 13, 19, 20, 21, 23.
,, inornatum, *M'Coy,*		×						20.
,, ornatum, *de Kon.*		×						11.
,, priscum, *Goldfuss*				×				55, 73.
,, new sp.		×						11.
,, sp....	(?)	×		(?)				10, 13, 19, 20, 21, 23.
Eulima, *Risso*								
,, phillipsiana, *de Kon.*		×						11.
Euomphalus, *Sowerby*								
,, carbonarius, *Sow.*	×	×						10, 11, 13, 20, 21, 22, 23, 50*c*.
,, radians, *de Kon.*		×						10, 11, (?) 13, 20, 23.
,, (?) serpens, *Phill.*				×				73.
,, tuberculatus, *Flem.*		×						38.
,, sp.		×						40.
Loxonema, *Phill.*								
,, constrictum, *Sow.*		×						11, 75.
,, elongatum, *de Kon.*		×						11.
,, Lefebvrei, *Leveillé*		×						75.
,, rugiferum, *Phill....*		×						11, 21, 22, (?) 74, 75.
,, scalaroideum, *Phill.*		×		×				11, 23, 55, 73, 75.
,, sp.	(?)	×		×				1, 18, 34, 36, 38, 40, 41, 50*g*, 55*a*, 58.
Macrochilina, *Phill.*								
,, acuta, *Sow,* ...	×	×		×				51, 56, 73, 75.
,, fusiformis, *Sow.*		×		×				29, 38, 55, 73.
,, imbricata, *Sow...*	×	×		×				13, (?) 22, 38, 51, 55, 73, 75.
,, michotiana, *de Kon.*		×		×				56, 73, 75.
,, sp.	×	×						10, 11, 14, 18*a*, 19, 20, 21, 22, 23, 40, 50*b*, 50*g*, 51, 55*a*, 55*c*, 58.
Microdoma, *Meek and Worthen*								
,, (Trochus) biserrata, *Phill.*		×						76.
Murchisonia, *d'Arch. & de Vern.*								
,, angulata, *Phill.*				×				73.
,, (Hypergonia) quadricarinata, *M'Coy*		×		×				73, 75.
,, *(Aclisoides) striatula* ; (*see* Aclisina)								
,, tricincta, *M'Coy*				×				73.
,, sp.	(?)	×		(?)				3, 40, 55*b*, 76.

SPECIES.	Lower.				Upper.			Locality Number.
	Calciferous Sandstone.	Carb. Limest. Series. Lower Limestones.	Carb. Limest. Series. "Edge Coals."	Carb. Limest. Series. Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
GASTEROPODA—*continued.*								
Narica, *Recluz*								
,, elliptica, *Phill.* ...		×						76.
,, variata, *Phill.* ...	×	×		×				18*a*, 50*b*, 55*a*, 75.
,, sp.	×							50*b*.
Naticopsis, *M'Coy*								
,, ampliata, *Phill.* ...				×				(?) 55.
,, elongata, *Phill.* ...		×		×				40, 73.
,, omaliana, *de Kon.*				×				73.
,, plicistria, *Phill.* ...		×		×				38, 40, 73, 75.
,, large sp.		×						41.
,, sp.	×	×		(?)				41, 50*e*, 50*f*, 55*c*, 58.
Pleurotomaria, *Defrance*								
,, (Ptychomphalus) atomaria, *Phill.*		×						10, 11, 13, 23.
,, contraria, *de Kon.*		×		×				40, 73.
,, monilifera, *Phill.*		×		×				29, 56, 73, 75.
,, (Baylea) Yvani, *Lev.*		×						75.
,, sp.	×	×		×				1, 3, 4, 11, 17, 20, 22, 36, 40, 50*b*, 53, 55*a*, 56, 57, 58, 75.
Porcellia, *Leveillé*								
,, armata, *Verneuil*				×				73.
Subulites, *Conrad*								
,, (Polyphemopsis) fusiformis, *Sow* ...				×				55, 55*c*.
PTEROPODA (?).								
Conularia, *Miller*								
,, quadrisulcata, *Sow.*		×						1, 13, 20, 22.
,, sp.	×	×						23, 50*g*.
CEPHALOPODA.								
Actinoceras, *Brown*								
,, giganteum, *Sow.*		×						22, (?) 23.
,, sp.		(?)						(?) 11.
Cyrtoceras, *Goldfuss*								
,, rugosum, *Flem.* ...	×	×		×				11, 13, 22, 23, 50*b*, 73.
,, unguis, *Phill.* ...		×						11.
,, sp.		×						10, 22.
Discites, *M'Coy*								
,, (Nautilus) leveilleauus, *De Kon.*		×						75.
,, ,, nodiferus, *Armst.*				×				73.

SPECIES.	LOWER.				UPPER.			Locality Number.
		Carb. Limest. Series.						
	Calciferous Sandstone.	Lower Limestones.	"Edge Coals."	Upper Limestones.	Millstone Grit.	Lower Coal-measures.	Mid. or Red Coal-measures.	
CEPHALOPODA—*continued.*								
Discites (Nautilus) quadratus, *Flem.*		×		×				10, 11, 12, 13, 14, 20, 39, 40, 56, 58.
,, ,, rotifer, *Salt.*						×		72.
,, ,, subsulcatus, *Phill.*		×						13.
,, ,, sulcatus, *Sow.*		×						30, 40, 75.
,, ,, sp. ...	×	×				×		22, 50*b*, 72.
Goniatites, *De Haan*								
,, striolatus, *Phill.* ...				×				56.
,, sp.	×	×		×				3, 9*a*, 10, 11, 13, 20, (?) 22, 50*f*, 57.
Nautilus, *Breyn.*								
,, canaliculatus, ...		×						75.
,, globatus, *Sow.* ...		×						75.
,, *nodiferus* (*see* Discites)								
,, sp.	×	(?)						3, 20, 50*f*.
Orthoceras, *Breyn.*								
,, attenuatum, *Flem.*		×		×		(?)		38, 56, 7?, 73.
,, cylindraceum, *Flem.*		×						11, (?) 13.
,, (?) laterale, *Phill.* (= ovale, *Phill.*)	×							50*a*.
,, lineale, *de Kon.* ...		×						38.
,, pyramidale, *Flem.*		×						11, (?) 13.
,, sulcatum, *Flem.* ...	×	×		×				1, 3, 10, 11, 12, 13, 14, 20, 21, 22, 24, 29 50*b*, 51.
,, ,, var. ...		×						20, 23.
,, undatum, *Flem.* ...	×	×						51, 74, 75.
,, sp.	×	×		×				15, 17, 18*a*, 19, 40, (?) 50*e*, 50*g*, 52, 55*c*, 58.
PISCES.								
Elasmobranchii —Ichthyotomi.								
Diplodus, *Agassiz*								
,, gibbosus, *Ag.* ...						×	×	66, 67, 68.
,, parvulus, *Traq.* ...	×							50*j*.
Pleuracanthus, *Agassiz*								
,, laevissimus, *Ag.*						×		68.
Selachii.								
Callopristodus, *Traq.*								
,, pectinatus, *Ag.*	×		(?)					(?) 16, 43, 50*j*
Cladodus, *Agassiz*								
,, mirabilis, *Ag.* ...	×	×						50*j*, 75.
,, striatus, *Ag.* ...		(?)						(?) 11.
,, sp.	×	×						1.
Cochliodont teeth		×						58.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
PISCES—*continued.*								
ius, *Agassiz*								
,, lobatus, *R. Eth., jun.* ...		×						1, 58.
,, serratus, *Owen*		×						11, 22, 58.
,, sp.		×						23.
Euphyacanthus, *Traquair*								
,, semistriatus, *Traq.*	×							50*j*.
Gyracanthus, *Agassiz*								
,, rectus, *Traq.*	×							43.
Helodus, *Agassiz*								
,, sp.						×		68.
Oracanthus, *Agassiz*								
,, armigerus, *Traq.*	×							50*j*.
Petalodus, *Owen*								
,, acuminatus, *Ag.* ...		×						1, 11, 13, 22, 41, 58, 74, 75.
,, sp.							×	72.
Petalorhynchus, *Agassiz*								
,, psittacinus, *Ag.*		×						41.
,, sp.		×						75.
Pleuroplax, *A. S. Woodward*								
,, sp.	×							
Pœcilodus, *Agassiz*								
,, Jonesi, *M'Coy* ...		×						1, 41.
,, sp.		×						21,
Pristodus, *Davis*								
,, Benniei, *R. Eth., jun.*		×						58.
,, falcatus, *Ag.* ...		×						41.
,, sp.		×						1.
Psammodus, *Agassiz*								
,, rugosus, *Ag.* ...		×						75.
,, ,, var. porosus, *Ag.*		×						1.
Psephodus, *Agassiz*								
,, magnus, *Ag.* ...		×						74.
,, sp....		×						22.
Sphenacanthus, *Agassiz*								
,, hybodoides, *Egerton*							×	66, 68.
,, sp.						×		68.
Tristychius, *Agassiz*								
,, arcuatus, *Ag.* ...	×							50*j*.
,, sp.								
Acanthodei.								
Acanthodes, *Agassiz*								
,, sp.	×					×	×	50*j*, 60, 66, 68.
Dipnoi—Sirenoidei.								
Ctenodus, *Agassiz*								
,, sp.						×	×	66, 68.

SPECIES.	Lower. Calciferous Sandstone.	Lower. Carb. Limest. Series. Lower Limestones.	Lower. Carb. Limest. Series. "Edge Coals."	Lower. Carb. Limest. Series. Upper Limestones.	Upper. Millstone Grit.	Upper. Lower Coal-measures.	Upper. Mid. or Red Coal-measures.	Locality Number.
PISCES—*continued.*								
Ostracodermi.								
Bothriolepis, *Eichwald* *								ii.
Teleostomi—Crossopterygii.								
Holoptychius, *Agassiz...* *								
,, nobilissimus, *Ag.*								i., iii., iv., v., vi., vii., viii., ix.
Cœlacanthus, *Agassiz*								
,, abdenensis, *Traq.*	×							50*j*.
,, elegans, *Newberry*						×		60, 68.
,, sp.	×	×						14, 23, 50*b*.
Megalichthys, *Agassiz*								
,, Hibberti, *Ag.* ...						×	×	66, 67, 68, 71.
,, sp.	×	×						43, 50*j*, 76.
Rhizodopsis, *Huxley*								
,, sauroides, *Will....*						×		(?) 23, 50*b*, 60, 68.
,, sp.	×	×	×			×	×	10, 20, 22, 25, 50*g*, 50*j*, 72.
Rhizodus, *Owen*								
,, sp.	×	×	×					13, 25, 42.
Strepsodus, *Hux. and Young*								
,, sauroides, *Ag.*, m.s.	×					×	×	60, 66, 68, 71, 72.
,, striatulus, *Traq....*	×							50*j*.
Actinopterygii.								
Cheirodus, *M'Coy*								
,, crassus, *Traq.* ...	×							50*j*.
Elonichthys, *Giebel*								
,, pectinatus, *Traq.*	×							50*j*.
,, Robisoni, *Hibbert*	×							32, 42, 46.
,, sp.	×							3*a*, 5*a*, 31.
Eurynotus, *Agassiz*								
,, crenatus, *Ag.* ...	×							3*a*, 31, 46, 50*j*.
Nematoptychius, *Traquair*								
,, Greenocki, *Ag.*	×		×					25, 46.
Rhadinichthys, *Traq.*								
,, ornatissimus, *Ag.*	×							31, 46.
Palæoniscid scales							×	66, 72.
Coprolites (of fish ?)				×		×	×	25, 29, 66.
AMPHIBIA.								
Labyrinthodontia.								
Anthracosaurus, *Huxley*								
,, Russelli, *Hux.*						×		68.
Loxomma, *Huxley*								
,, Allmani, *Hux.* ...						×		68.

* Upper Old Red Sandstone.

C. Special List of the Fossils

Found in each of the Subdivisions of the Stratigraphical Series.

Upper Old Red Sandstone.

Holoptychius, *Agassiz*
,, nobilissimus, *Agassiz* ... i., iii., iv., v., vi., vii., viii., ix.
Bothriolepis, *Eichwald*
,, sp. ... ... ii.

Calciferous Sandstone Series.

	Below Burdiehouse Limestone.	Burdiehouse Limestone.	Between Burdiehouse Limestone and 1st Abden Limestone.	1st Abden Limestone and Shales.	2nd Abden Limestone and Shales.
Adiantites antiquus		×			
Asterocalamites scrobiculatus		×	×		
Calymmatotheca affinis		×	×	×	
,, bifida		×			
Cardiopteris, sp.				×	
Cheirostrobus pettycurensis			×		
,, sp., No. 1			×		
,, sp., No. 2			×		
Cordaites sp.		×			
Heterangium Grievi			×		
Lepidodendron veltheimianum	×	×	×		
,, sp.			×		
Lepidophloios scoticus		×	×		
Lepidophyllum lanceolatum		×			
,, sp.	×				
Lepidostrobus comosus		×			
,, variablis		×			
,, sp.	×	×			
Lyginodendron sp.			×		
Rachiopteris duplex			×		
,, allied to Oldhami			×		
,, sp.			×		
Sphenophyllum insigne			×		
,, tenerrimum		×			
Sphenopteris crassa		×			
,, Dunsi		×			
,, (Rhodea) Hochstetteri ...		×			
,, moravica		×			
,, sp.				×	
Stigmaria sp.		×	×		
Sporangia			×		
Trigonocarpus sp.	×				
Archæodiscus Karreri...				×	

	Below Burdiehouse Limestone.	Burdiehouse Limestone.	Between Burdiehouse Limestone and 1st Abden Limestone.	1st Abden Limestone and Shales.	2nd Abden Limestone and Shales.
CALCIFEROUS SANDSTONE—*cont'd.*					
Climacammina antiquua				×	×
Endothyra Bowmani				×	×
,, crassa				×	×
,, globulus				×	×
,, macella				×	
,, obliqua				×	
,, ornata				×	
,, radiata				×	
Stacheia congesta				×	
,, pupoides				×	
,, polytrematoides				×	
Textularia eximia					×
,, gibbosa				×	
Trochammina incerta				×	
Valvulina decurrens				×	
,, palæotrochus				×	×
,, plicata				×	
,, rudis				(?)	
,, Youngi				×	
Onion-like bodies (? foraminifera)				×	
Clisiophyllum sp.				×	×
Cyclophyllum fungites					×
Lithostrotion irregulare					
Zaphrentis sp.				×	
Crinoid remains				×	×
Archæocidaris (plates and spines)				×	×
Hydreionocrinus globularis					×
Serpulites carbonarius					×
,, sp.	×				
Spirorbis caperatus				×	×
,, pusillus		×			
Argillæcia æqualis	×				
Bairdia ampla				×	
,, brevis				×	
,, curta				×	
,, ,, var.				×	
,, elongata				×	
,, Hisingeri				×	×
,, plebeia				×	×
,, subcylindrica				×	
,, subelongata				×	×
,, submucronata...				×	×
Beyrichia fastigiata	×				
,, sp.				×	
Beyrichiopsis fimbriata	×				
,, ,, var.	×				
Bythocypris cornigera...				×	
,, cuneola				×	
Cythere superba	×				
Cytherella attenuata	×				
,, extuberata...	×				
Kirkbya permiana				×	
,, plicata	×				
,, spinosa				×	
,, spiralis	×				

	Below Burdiehouse Limestone.	Burdiehouse Limestone.	Between Burdiehouse Limestone and 1st Abden Limestone.	1st Abden Limestone and Shales.	2nd Abden Limestone and Shales.
CALCIFEROUS SANDSTONE—*cont'd.*					
Kirkbya Urei				×	
Leperditia Okeni	×	×		×	
,, scotoburdigalensis		×			
,, suborbiculata		×		(?)	
Eoscorpius sp.				×	
Fenestella sp.				×	
Hyphasmopora Buski				×	
Rhabdomeson sp.				×	
Sulcoretepora parallela				×	
,, sp.					×
Athyris ambigua				×	
Chonetes laguessiana					×
,, polita...				(?)	
Crania sp.					×
Discina nitida				×	×
Lingula mytiloides	×			×	
,, squamiformis...	×			×	×
,, sp.				×	×
Orthis Michelini				×	
,, resupinata				×	×
,, sp.				×	×
Productus complectens					×
,, costatus					(?)
,, longispinus...				×	×
,, mesolobus				×	
,, punctatus					×
,, scabriculus...				×	
,, semireticulatus				×	×
,, sp.				×	
Rhynchonella pleurodon*				×	
,, sp.				×	
Spirifera duplicicosta					×
,, Urei				×	
,, sp.				×	×
Spiriferina cristata					×
Streptorhynchus crenistria				×	×
,, sp.				×	
Allorisma maxima				×	
Anthracomya lævis, var. scotica		×	×		
Avicula sp., (? new)				×	
Aviculopecten cœlatus				×	
,, dissimilis				×	
,, granosus					(?)
,, hemisphæricus					×
,, interstitialis				×	
,, ornatus				×	×
,, Sowerbyi				×	
,, subconoides				×	
,, sp.				×	×
Edmondia Josepha				×	
,, Lyelli				×	
,, rudis or unioniformis (?)				×	
,, sp.				×	
Lithodomus carbonarius				×	
Modiola sp.	×			×	

* Very common.

	Below Burdiehouse Limestone.	Burdiehouse Limestone.	Between Burdiehouse Limestone and 1st Abden Limestone.	1st Abden Limestone and Shales.	2nd Abden Limestone and Shales.
CALCIFEROUS SANDSTONE—*cont'd.*					
Myalina Flemingi				×	
,, sublamellosa				×	
,, sp.			×	×	×
Naiadites crassa				×	
,, obesa	×				
,, sp.	×		×	×	
Nucula gibbosa				×	
Nuculana attenuata				×	(?)
,, sp.					×
Parallelodon divisus				×	
,, sp.				×	
Protoschizodus axiniformis				×	
,, sp.			(?)		
Pterinea (?)				(?)	
Pteronites persulcatus				×	
,, ,, (young of ?)				×	
,, sulcatus				×	
,, sp.			×	×	×
Sanguinolites abdenensis				×	
,, striatolamellosa				×	
,, sp.			×		
Schizodus sp.					×
Sedgwickia suborbicularis				×	×
Solenomya primæva				×	
,, sp.				×	
Aclisina striatula				×	
Bellerophon decussatus			×	×	×
,, Dumonti				×	
,, striatus				×	
,, Urei				×	
,, sp.					×
Dentalium sp.				(?)	×
Euomphalus carbonarius				×	
Loxonema sp.				(?)	
Macrochilina acuta					×
,, imbricata					×
,, sp.				×	
Murchisonia sp.			×	(?)	×
Narica variata				×	
,, sp.				×	
Naticopsis sp.				×	
Pleurotomaria sp.			×	×	
Conularia sp.				×	
Cyrtoceras rugosum				×	
Discites sp.				×	
Goniatites sp.			(?)	×	
Nautilus sp.			×	×	
Orthoceras laterale				(?)	
,, sulcatum			×	×	×
,, undatum					×
,, sp.				×	
Acanthodes sp.				×	
Callopristodus pectinatus		×		×	
Cheirodus crassus				×	
Cladodus mirabilis				×	

	Below Burdiehouse Limestone.	Burdiehouse Limestone.	Between Burdiehouse Limestone and 1st Abden Limestone.	1st Abden Limestone and Shales.	2nd Abden Limestone and Shales.
CALCIFEROUS SANDSTONE—*cont'd.*					
Cladodus sp.				×	
Coelacanthus abdenensis				×	
,, sp.				×	
Diplodus parvulus				×	
Elonichthys pectinatus				×	
,, Robisoni		×			
,, sp.	×	×			
Euphyacanthus semistriatus				×	
Eurynotus crenatus	×	×		×	
Gyracanthus rectus		×			
Megalichthys sp.		×		×	
Nematoptychius Greenocki		×			
Oracanthus armigerus				×	
Pleuroplax sp.				×	
Rhadinichthys ornatissimus		×			
Rhizodopsis sauroides...				×	
,, sp.				×	
Rhizodus sp.		×		×	
Strepsodus striatulus				×	
Tristychius arcuatus				×	
Fish-remains (obscure)			×		
Palæoniscid scales	×				
Shark shagreen...	×				
Coprolites	×				

Hurlet Limestone.

Endothyra Bowmani.
,, crassa.
Stacheia polytrematoides.
,, pupoides.
Trochammina incerta.
Valvulina palæotrochus.
,, ,, var. compressa.
,, Youngi.
,, ,, var. contraria.
Onion-like bodies.
Acanthospongia Smithi.
Ascodictyon radians.
Hyalostelia parallela.
Sponge borings in Chonetes.
Palæocoryne.
Amplexus coralloides.
,, spinosus.
,, sp.
Aspidophyllum sp.
Aulopora sp.
Chætetes tumidus.
Clisiophyllum coniseptum.
,, turbinatum.
Cyathaxonia cornu.
Cyathophyllum paracida.
Cyclophyllum fungites.
Dibunophyllum sp.
Favosites parasitica.
Heterophyllia granulata.
,, Lyelli.
Lithostrotion junceum.
Lonsdaleia sp.
Lophophyllum parvulum.
,, sp.
Palæacis compressa.
,, cyclostoma.
Syringopora sp.
Zaphrentis cliffordiana ?
,, Enniskilleni.
,, Griffithsi.
,, sp.
Archæocidaris Urei.
Astrocrinites Benniei.
Cupressocrinus impressus ?
Hydreionocrinus globularis.
,, sp.
Platycrinus, near arenosus.
,, trigintidactylus.
,, sp.
Poteriocrinus crassus.

Poteriocrinus tenuis.
Holothurian plates, etc.
Ortonia carbonaria.
Serpulites carbonarius.
,, sp.
Spirorbis ambiguus.
,, caperatus.
,, spinosus ?
,, sp.
Bairdia ampla.
,, brevis.
,, curta.
,, curta var.
,, grandis.
,, Hisingeri.
,, plebeia.
,, ,, var.
,, subelongata
,, submucronata.
,, sp.
Beyrichia radiata.
Beyrichiella (?) ventricornis.
Bythocypris cornigera.
Cypridina sp.
Cytherella sp.
Kirkbya costata.
,, permiana.
,, umbonata.
,, Urei.
Leperditia armstrongiana.
,, Okeni.
,, ,, var. acuta.
Phillipsia Eichwaldi,
,, ,, var. mucronata.
Ceriopora sp.
Diastopora megastoma.
,, new sp.
Fenestella Morrisii.
,, multiporata.
,, plebeia.
,, undulata.
,, new sp.
Glauconome pulcherrima.
Hippothoa Hincksi, m.s.
Polypora tuberculata.
,, sp.
Rhabdomeson rhombiferum.
,, sp.
Sulcoretepora parallela.
Thamniscus pustulosus ?
Athyris ambigua.
,, Roysii.
Chonetes buchiana.
,, comoides.
,, laguessiana.
,, polita.
,, sp.
Crania quadrata.
Discina nitida.
Lingula mytiloides.
,, squamiformis.
,, sp.
Orthis Michelini.
,, resupinata.
,, sp.
Productus aculeatus.
,, complectens.
Productus, near costatus.
,, fimbriatus.
,, giganteus.
,, latissimus.
,, longispinus.
,, margaritaceus.
,, mesolobus.
,, punctatus.
,, pustulosus.
,, scabriculus.
,, semireticulatus.
,, ,, var. Martini.
,, youngianus.
Retzia radialis.
Rhynchonella pleurodon.
Spirifera carlukensis ?
,, duplicicosta.
,, glabra.
,, lineata.
,, ovalis.
,, trigonalis.
,, ,, var. bisulcata.
,, ,, var.
,, Urei.
Spiriferina cristata.
,, ,, var. octoplicata.
,, sp.
Streptorhynchus crenistria.
,, ,, var.
Terebratula hastata.
,, sacculus.
,, vesicularis.
,, sp.
Anthracomya Phillipsi.
Aviculopecten arenosus.
,, cœlatus.
,, concavus.
,, dissimilis.
,, docens.
,, fimbriatus.
,, granosus ?
,, interstitialis.
,, ornatus.
,, planoradiatus ?
,, Sowerbyi.
,, sp.
Conocardium aliforme.
,, sp.
Ctenodonta sinuosa.
Cypricardella acutocarinata ?
,, concentrica.
,, parallela.
,, rectangularis.
,, sp.
Edmondia Josepha.
,, rudis.
,, scalaris.
,, sulcata ?
,, unioniformis.
Modiola elongata.
,, sp.
Myalina sp.
Mytilomorpha rhombea.
Naiadites crassa.
Nucula acuta.
,, near acuta.
,, gibbosa.

Nucula lævirostrum.
,, luciniformis.
Nuculana attenuata.
,, brevirostrum.
,, lævistriata.
Parallelodon divisus ?
,, semicostatus.
,, sp.
Pinna flabelliformis.
Posidonomya corrugata.
,, sp.
Protoschizodus axiniformis.
,, obliquus.
Pteronites sp.
Sanguinolites angustatus.
,, costellatus.
,, iridinoides.
,, striatolamellosus.
,, striatus.
,, tricostatus
,, near visètensis ?
Sedgwickia gigantea ?
,, suborbicularis.
Solenomya excisa.
,, primæva.
Aclisina elongata.
,, striatula.
Acroculia neritoides.
,, vetusta.
,, sp.
Bellerophon decussatus.
,, Oldhami.
,, striatus.
,, Urei.
Dentalium ingens.
,, inornatum.
,, ornatum.
,, new sp.
Eulima phillipsiana.
Euomphalus carbonarius.
,, radians.
,, tuberculatus.
Loxonema constrictum.
,, elongatum.
,, Lefebvrei.
,, rugiferum.
,, scalaroideum.
,, sp.
Macrochilina acuta.
Macrochilina fusiformis.
,, imbricata.
,, michotiana.
Microdoma (Trochus) biserrata.
Murchisonia quadricarinata.
Narica elliptica.
,, variata.
Naticopsis plicistria.
,, sp.
Pleurotomaria atomaria.
,, monilifera.
,, Yvanii.
,, sp. large.
Conularia quadrisulcata.
Actinoceras ?
Cyrtoceras rugosum.
,, unguis.
Discites leveilleanus.
,, quadratus.
,, subsulcatus.
,, sulcatus.
Goniatites sp.
Nautilus canaliculatus.
,, globatus.
Orthoceras attenuatum.
,, cylindraceum.
,, lineale.
,, pyramidale.
,, sulcatum.
,, ,, var.
,, undatum.
Cladodus mirablis.
,, striatus ?
,, sp.
Cochliodont teeth.
Ctenoptychius lobatus.
,, serratus.
Megalichthys sp.
Petalodus acuminatus.
Petalorhynchus psittacinus.
,, sp.
Pœcilodus Jonesi.
Pristodus Benniei.
,, falcatus.
,, sp.
Psammodus rugosus, var. porosus.
Psephodus magnus.
Rhizodopsis sp.

Hosie Limestones.

Archæodiscus Kerreri.
Endothyra globulus.
,, obliqua.
Nodosinella concinna.
Saccammina sp.
Stacheia congesta.
,, fusiformis.
,, polytrematoides ?
,, pupoides.
Trochammina anceps.
,, incerta.
Valvulina decurrens.
,, palæotrochus.
,, ,, var. compressa.
,, Youngi.
,, ,, var. contraria.
Ascodictyon radians.
Hyalostelia parallela.
Peronidella sparsa.
Sponge borings ?
Palæocoryne sp.
Amplexus ibicinus.

Amplexus spinosus.
Aulopora campanulata.
,, sp.
Chætetes tumidus.
,, sp.
Cladochonus Michelini.
Clisiophyllum ?
Cyathaxonia cornu ?
Favosites parasitica.
Lophophyllum eruca.
,, parvulum ?
Lithostrotion sp.
Michelinia, near megastoma.
Palæacis compressa.
,, cyclostoma.
Zaphrentis, near centralis.
,, ,, cliffordiana.
,, Enniskilleni.
Archæocidaris plates and spines.
Hydreionocrinus globularis ?
Poteriocrinus crassus.
,, nuciformis.
,, new sp. near nuciformis.
Platycrinus trigintidactylus.
Achistrum Nicolsoni.
Cheirodota ? Traquairi.
Ortonia ?
Serpulites carbonarius.
,, membranaceus.
Spiroglyphus sp.
Spirorbis globosus.
,, pusillus.
,, spinosus.
Vermilia sp.
Bairdia ampla.
,, brevis.
,, plebeia.
,, submucronata.
,, ,, var.
Beyrichia crinita ?
,, radiata.
,, varicosa.
Beyrichiella ventricornis.
Bythocypris cornigera.
,, cuneola.
,, cuneolina.
Cythere sp.
Cytherella ?
Kirkbya obsoleta.
,, permiana.
,, striolata ?
,, umbonata.
,, Urei.
Leperditia Okeni.
Dithyrocaris (mandibles).
Phillipsia sp.
Calamopora (Carinella) sp.
Ceriopora interporosa.
Diastopora megastoma.
Fenestella sp.
Glauconome elegantula.
,, sp.
Goniocladia cellulifera.
,, ,, ? or a new form.
,, sp.
Hyphasmopora (Rhombopora) Benniei.
,, ,, Buski.
Rhabdomeson gracile.
,, rhombiferum.
Sulcoretepora ?
Athyris ambigua.
,, Roysi.
Chonetes laguessiana.
,, polita.
Crania quadrata.
Discina nitida.
Lingula mytiloides.
Orthis Michelini.
,, resupinata.
Productus aculeatus.
,, complectens.
,, costatus.
,, elegans.
,, longispinus.
,, punctatus.
,, pustulosus.
,, scabriculus.
,, semireticulatus.
,, ,, var. Martini.
,, youngianus.
,, sp.
Retzia radialis.
Rhynchonella pleurodon.
,, sp.
Spirifera carlukensis.
,, duplicicosta.
,, glabra.
,, lineata, var.
,, ovalis.
,, trigonalis.
,, ,, var. bisulcata.
,, Urei.
,, sp.
Spiriferina cristata.
,, ,, var. octoplicata.
Streptorhynchus crenistria.
Strophomena analoga, var. distorta.
Terebratula sacculus, var.
Aviculopecten cœlatus.
,, concavus.
,, dissimilis.
,, docens.
,, ornatus ?
,, Sowerbyi.
Conocardium aliforme.
Cypricardella concentrica.
,, parallela.
,, rectangularis ?
Cypricardia sp.
Edmondia unioniformis.
,, near scalaris.
,, sp.
Lithodomus lingualis.
,, lithodomoides.
Nucula gibbosa.
,, lævirostrum.
,, lineata=N. scotica.
Nuculana attenuata.
,, brevirostrum.
,, lævistriata.
Parallelodon bistriatus ?
,, semicostatus.
,, new sp.
Pecten sp.

Pinna flabelliformis.
Protoschizodus axiniformis.
Pterinea or Pteronites.
Sanguinolites costellatus.
,, oblongus ?
,, tricostatus ?
Schizodus sp.
Sedgwickia suborbicularis.
Aclisina gracilis.
Bellerophon decussatus.
,, Oldhami.
,, striatus.
,, Urei.
Dentalium ingens.
,, sp.
Euomphalus carbonarius.
,, radians.
,, sp.
Loxonema rugiferum.
,, scalaroideum.
Macrochilina imbricata ?
,, sp.
Murchisonia striatula ?
,, sp.
Narica variata.
Naticopsis elongata.
,, plicistria.
Pleurotomaria atomaria.
,, contraria.
Conularia quadrisulcata.
,, sp.
Actinoceras giganteum.
Cyrtoceras rugosum.
,, sp.
Discites quadratus.
,, subsulcatus.
,, sulcatus.
,, sp.
Goniatites ?
Orthoceras cylindraceum or pyramidale.
,, sulcatum.
,, sp.
Cœlacanthus sp.
Ctenoptychius serratus, var.
,, sp.
Petalodus acuminatus.
Pœcilodus sp.
Rhizodus sp.
Rhizodopsis sp.
Psephodus sp.

Edge Coal Series.

Lepidodendron sp.
Sphenopteris sp.
Stigmaria sp.
Spirorbis pusillus.
Carbonia fabulina.
Entomostraca.
Lingula squamiformis var.
Anthracomya Phillipsi.
Callopristodus pectinatus ?
Nematoptychius Greenocki.
Rhizodopsis sp.
Rhizodus sp.

Index Limestone.

(Chiefly supplied by Mr. J. W. Kirkby.)

Bairdia sp.
Beyrichia bradyana.
Bythocypris cuneola.
,, phillipsiana, var. carbonica.
Bythocythere youngiana ?
Cytherella Benniei.
,, sp.
Kirkbya scotica.
Ulrichia bituberculata.
Streptorhynchus crenistria.
Terebratula sacculus var.
Nuculana lævistriata.
Schizodus (?), small.
Bellerophon decussatus.

Gair Limestone.

Calamites sp.
Stigmaria sp.
Endothyra Bowmani.
,, globulus.
,, radiata.
Stacheia sp.
Trochammina incerta.
Valvulina decurrens.
Hyalostelia parallela.
Palæocoryne.
Monticulipora tumida.
Poteriocrinus crassus.
Archæocidaris sp.
Ortonia carbonaria.
,, sp.
Serpulites sp.
Spirorbis sp.
Bairdia plebeia.
,, subelongata.
,, submucronata.

Bairdia sp.
Beyrichia radiata.
,, tuberculospinosa.
,, sp.
Bythocypris cuneola.
,, cuneolina.
,, phillipsiana, var. carbonica.
Cytherella recta.
Kirkbya permiana.
,, rigida.
,, spinosa.
Leperditia acuta.
,, inornata ?
,, Okeni.
,, ,, vars.
Dithyrocaris ?
Phillipsia sp.
Diastopora sp.
Fenestella sp.
Glauconome sp.
Goniocladia cellulifera.
Thamniscus pustulosus ?
Athyris ambigua.
,, Roysii.
Chonetes laguessiana.
Discina nitida.
Lingula mytiloides.
,, sp.
Orthis resupinata.
,, sp.
Productus complectens.
,, costatus.
,, giganteus.
,, latissimus.
,, longispinus.
,, scabriculus.
,, semireticulatus.
Rhynchonella pleurodon.
,, sp.
Spirifera trigonalis.
,, ,, var. bisulcata.
,, ,, var.
,, ovalis or pinguis.
,, Urei.
Spiriferina cristata, var. octoplicata.
Streptorhynchus crenistria.
Aviculopecten arenosus ?
,, ornatus.
,, sp.
Cardiomorpha oblonga.
Ctenodonta sinuosa.
Edmondia Josepha.
,, Lyelli.
,, rudis.
,, unioniformis.
Modiola Macadami.
Myalina Flemingi ?
,, sp.
Nucula gibbosa.
Nuculana attenuata.
,, lævistriata.
Protoschizodus axiniformis.
,, obliquus.
Pteronites persulcatus.
,, sulcatus.
Sanguinolites striatolamellosa.
Schizodus ?
Solenopsis minor.
Acroculia sp.
Bellerophon decussatus.
,, leveilleanus.
,, striatus.
,, Urei.
Dentalium priscum.
,, sp.
Loxonema scalaroideum.
,, sp.
Macrochilina fusiformis.
,, imbricata.
Murchisonia striatula.
,, sp. ?
Narica variata.
Naticopsis ampliata ?
,, sp.
Pleurotomaria monilifera.
Subulites (Polyphemopsis) fusiformis.
Orthoceras sulcatum.
,, sp.
Coprolites.

Levenseat Limestone.

Zaphrentis Phillipsi.
Platycrinus sp.
Poteriocrinus ventricosus ?
,, sp.
Serpulites carbonarius.
Beyrichia radiata.
Bythocypris cuneola.
,, phillipsiana var. carbonica.
Cytherella Benniei.
,, recta.
Kirkbya permiana, var.
,, Urei.
,, sp.
Leperditia Okeni.
Youngia rectidorsalis ?
Phillipsia Eichwaldi var mucronata.
Ceriopora similis.
Diastopora megastoma.
,, sp.
Athyris ambigua.
,, Roysii.
Chonetes laguessiana.
Discina nitida.
Lingula mytiloides
Orthis Michelini.
Productus semireticulatus var. concinnus.
,, sinuatus.
,, sp.
Spirifera trigonalis var. bisulcata.
,, Urei.
Streptorhynchus crenistria.
Aviculopecten sp.

Cardiomorpha sp.
Conocardium sp.
Cypricardella rectangularis.
Edmondia Josepha.
,, unioniformis ?
Nucula gibbosa.
,, lævirostrum.
Nuculana attenuata.
Parallelodon semicostatus.
,, sp.
Protoschizodus axiniformis.
Acroculia neritoides.
Bellerophon decussatus.
,, leveilleanus.
,, Urei.
Dentalium priscum.
Euomphalus serpens ?
Loxonema scalaroideum.
Macrochilina acuta.
Macrochilina fusiformis.
,, imbricata.
,, michotiana.
Murchisonia angulata.
,, quadricarinata.
,, tricincta.
Naticopsis elongata.
,, omalina.
,, plicistria.
Pleurotomaria contraria.
,, monilifera.
,, sp.
Porcellia armata.
Cyrtoceras rugosum.
Discites quadratus.
Goniatites striolatus.
,, sp.
Nautilus (Discites) nodiferus.
Orthoceras attenuatum.

Coal Measures.—The equivalents of "The Lower Coal Measures" of England (chiefly supplied by Mr. J. W. Kirkby).

Alethopteris decurrens.
,, lonchitica.
Annularia radiata.
Calamites Cisti.
,, nodosus.
,, ramosus.
,, Suckowi.
,, varians.
,, sp.
Calamocladus equisetiformis
Cordaianthus Pitcairniæ.
Cordaites principalis.
,, sp.
Dactylotheca plumosa, forma crenata.
Eremopteris artemisiaefolia.
Lepidodendron ophiurus.
,, sp.
Lepidophloios acerosus.
Lepidostrobus variabilis.
,, sp.
Mariopteris muricata, forma nervosa.
Neuropteris gigantea.
,, heterophylla.
Palæostachya pedunculata.
Pinnularia capillacea.
Renaultia Footneri.
,, microcarpa.
Sigillaria Brardi.
,, scutellata.
,, sp.
Sphenophyllum cuneifolium.
,, sp.
Sphenopteris acutifolia.
,, furcata.
,, latifolia.
,, Laurenti.
,, obtusiloba.
,, Schillingsi.
Stigmaria ficoides.
Trigonocarpus Parkinsoni.
,, sp.
Macrospores.
Actinocrinus ? (stems).
Spirorbis pusillus.
Carbonia fabulina.
,, rankiniana.
Eoscorpius anglicus.
,, tuberculatus.
Myriapod.
Discina nitida.
Lingula mytiloides.
,, squamiformis.
Productus semireticulatus var. Martini.
Anthracomya Wardi.
,, Williamsoni
,, sp.
Carbonicola acuta.
,, aquilina.
,, turgida.
Naiadites (Anthracoptera) carinata.
,, modiolaris.
,, quadrata.
Sanguinolites sp.
Aclisina (Murchisonia) striatula.
Bellerophon decussatus.
,, Urei.
Discites rotiferus.
,, sp. with longitudinal ribs.
,, sp. smooth.
Orthoceras attenuatum ?
Acanthodes sp.
Coelacanthus elegans.
Ctenodus sp.
Diplodus gibbosus.
Helodus sp.
Megalichthys Hibberti.
Pleuracanthus laevissimus.
Rhizodopsis sauroides.
,, sp.
Sphenacanthus sp.
Strepsodus sauroides.
Anthracosaurus Russelli.
Loxomma Allmani.
Coprolites.
Various tracks.

Red Coal Measures.—The equivalents of "The Middle Coal Measures" of England (supplied by Mr. J. W. Kirkby).

Alethopteris aquilina.
Calamites ramosus.
,, Suckowii.
,, sp.
Calamocladus equisetiformis.
Cordaites sp.
Lepidodendron ophiurus.
,, c/f. rimosum.
Lepidophyllum lanceolatum.
Lepidostrobus variablis.
Mariopteris muricata.
Neuropteris rarinervis.
,, Scheuchzeri.
Pecopteris Miltoni.
Rhabdocarpus sulcatus.
Sigillaria camptotænia.
,, monostigma.
Sphenophyllum emarginatum (?).
Trigonocarpus Parkinsoni, forma olivæformis.

Bellinurus trilobitoides.
Eurypterus mammatus.
Carbonia fabulina.
,, rankiniana.
,, secans.
Leaia Leidyi.
Prestwichia anthrax.
Anthracomya modiolaris ?
,, Wardi.
Acanthodes sp.
Ctenodus sp.
Diplodus gibbosus.
Megalichthys Hibberti.
Palaeoniscid scales.
Petalodus sp.
Rhizodopsis sp.
Sphenacanthus hybodoides.
Strepsodus sauroides.
Coprolites.

Post-Tertiary.*—Glacial Lake deposits exposed in Railway cuttings near Dronachy Burn, about 1 mile west of Auchertool.

Amblystegium fluvitans.
Aulacomnium turgidum.
Distichium capillaceum.
Thalictrum flavum ?
Ranunculus aquatilis.
Viola palustris ?
Hippuris vulgaris.
Œnanthe.
Menyanthes trifoliata.
Betula nana.
Salix herbacea.
,, polaris.
,, reticulata.
Empetrum nigrum.

Potamegeton 2 sp.
Eleocharis palustris.
Scirpus pauciflorus.
,, fluitans ?
Carex 2 sp.
Daphnia pulex (eggs of).
Beetle, (jaws of).
Erigone sp. (spider).
Apus (Lepidurus) glacialis.—Many specimens consisting of detached mandibles, maxillæ, body segments, etc.
Pisidium sp.
Lymnea sp.

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* See "The Origin of the British Flora," by Clement Reid, p. 65.

PART II. PETROGRAPHICAL.

NOTES ON THE PETROGRAPHY OF THE IGNEOUS ROCKS OF THE LOWER OLD RED SANDSTONE OF THE EASTERN OCHIL HILLS. BY HERBERT KYNASTON, B.A.

I. LAVAS.

(*a*) *Andesites.*

[8765.]* 350 yards north of Bein Inn, Glen Farg. A dark purplish pyroxene-andesite, with amygdules of silica. Phrenocrysts of plagioclase, and enstatite with bronze-like lustre, may be seen with the naked eye. Under the microscope the felspar is seen to occur in elongated lath-shaped individuals, often with rather ragged outline, which are slightly decomposed and much cracked. They are probably labradorite. The pyroxene phenocrysts appear to be mainly represented by greenish bastite-like pseudomorphs after enstatite, which show transverse cracks, a distinct pleochroism, and straight extinction. The distinctness of the pleochroism may possibly indicate an enstatite slightly more ferriferous than that usually characteristic of the pyroxene-andesites. The ground-mass consists of lath-shaped plagioclases, augite grains, magnetite, and some greenish alteration-products. This is rather a basic type of *Andesite.*

[8766.] Same locality. A similar rock. The green fibrous pseudomorphs after enstatite are well seen, and the pleochroism is well marked. *Enstatite-Andesite.*

[8768.] Roadside, a little north of sill (*see* No. 8767) and south of where the road crosses the Farg in Glen Farg. A dark purple andesite, rich in plagioclase phenocrysts. The phenocrysts consist of lath-shaped crystals and crystal-groups of labradorite, and pale greenish pseudomorphs after olivine (?), showing good idiomorphism and irregular cracks filled with iron-ore. The groundmass consists of felspar microlites, small pyroxene granules, and magnetite.

[8771.] A sample of the prevalent type of andesite in Glen Farg. This again is rather a basic andesite. It contains phenocrysts of plagioclase (labradorite), some augite and olivine (?) pseudomorphs, in a fine microlitic groundmass. There are also some small amygdales containing silica.

[8868.] Chief quarry at west end of Newburgh, Fife. The phenocrysts consist of elongated crystals of plagioclase (labradorite), pale greenish fibrous pseudomorphs after enstatite, giving slight pleochroism, and a pale brownish augite in irregular grains. The groundmass is decidedly more coarse-grained than is usual in the andesites. It is micro-crystalline, and consists mainly of plagioclase, small augite grains, and some interstitial quartz. There also seems to be a small quantity of

* The numbers prefixed to the descriptions of the rocks refer to the microscopic slides in the collection of the Geological Survey.

interstitial alkali-felspar. Iron-ores (magnetite and hematite) are accessory. The rock may be called an *Enstatite-augite-andesite.*

[8869.] Lowest lava behind Newburgh. A similar type of andesite to the last, but apparently richer in ferromagnesian constituents. A good deal of alteration has taken place, with the production of carbonates. The plagioclase phenocrysts are similar to those of the preceding rock. The ferromagnesian phenocrysts consist of pseudomorphs after augite and enstatite (?). The latter do not show the characteristic fibrous structure, but are of a yellowish colour, and give a minute aggregate polarisation between crossed nicols, probably being altered into carbonates and limonite. The groundmass is micro-crystalline, and consists of plagioclase, some interstitial alkali-felspar (?), and quartz. Iron-ores are also present. The rock is a *Pyroxene-andesite.*

[8870.] Andesite, east of Lighthouse, Tayport. A much more compact type of andesite, but rather decomposed. The microscope shows small plagioclase phenocrysts and altered pyroxenes in a groundmass consisting of numerous plagioclase microlites, embedded in a brownish interstitial matter, which was probably originally glassy. Iron-ores are accessory, and often occur in irregular patches. *Pyroxene-andesite.*

[8871.] Andesite, Jock's Hole, west of south end of Tay Bridge. Consists of numerous lath-shaped plagioclases of both larger and smaller varieties, and irregular grains of altered pyroxene, in a brownish glassy base. Amygdales of varied shape are also seen, filled with silica and carbonates. *Pyroxene-andesite.*

[8872.] Andesite, of the prevalent type of the district, Upper Coul, east of Auchterarder, Perth. The phenocrysts consist of plagioclase, augite, enstatite, and olivine pseudomorphs. The augite has been a good deal altered into carbonates. The enstatite is in small crystals, showing slight pleochroism. The olivine pseudomorphs are more or less idiomorphic, and the alteration is that characteristic of the more ferruginous varieties met with in the more basic andesites. The groundmass consists mainly of small felspar microlites and a greyish brown interstitial matter. *Enstatite-augite-andesite.*

[8873.] Shore, 200-300 yards from where railway leaves cutting, west of Tayport; specimen taken from centre of flow. The slide shows no conspicuous felspar phenocrysts. Fairly numerous reddish and reddish-yellow pseudomorphs after olivine (?) are seen in a groundmass consisting of small plagioclase laths, altered pyroxene grains, magnetite, and brownish interstitial matter. There is a rude tendency to flow-structure observable in the arrangement of the plagioclases of the groundmass.

[8874.] Platy rock showing flow-structure, West Lighthouse, Tayport. A very compact and rather basic type of andesite. Under the microscope there are no signs of definite phenocrysts, except an occasional pseudomorph apparently after pyroxene. The rock consists essentially of small plagioclase microlites and small brownish granules, probably pyroxene. Flow structure is indicated by the orientation of the felspars. Magnetite is accessory, and frequently forms irregular patches.

[8875.] Basic Andesite (?). Quarry opposite Freeland Lodge, Forgandenny, Perth. A fine-grained basic type of andesite. Under the microscope the rock is seen to consist of larger and smaller lath-shaped plagioclases, greenish and slightly fibrous pseudomorphs after pyroxene, possibly enstatite, and small augite granules, belonging to the generation of the smaller felspars. A few larger grains of unaltered augite are

also present, and magnetite grains are fairly numerous. The smaller plagioclase individuals are closely packed together with their long axes arranged more or less parallel, indicating flow structure.

[8876.] From the top of one of the andesite flows, Shore, Tayport. A fine-grained dark purplish rock. A basic type of andesite without porphyritic felspars, but containing phenocrysts of pseudomorphs apparently after olivine. The groundmass consists of plagioclase microlites, showing flow structure, augite grains, magnetite, and some brownish undifferentiated matter, which was probably originally glassy.

[8877.] From quarry on roadside, Balhelvie, east from Newburgh. The microscope shows phenocrysts of altered plagioclase in a groundmass of felspar microlites embedded in a brown (glassy?) base. The rock is too decomposed for the recognition of the ferromagnesian constituents. A few amygdales are also present.

[8880.] Mount Stewart, west from Bridge of Earn. This rock consists essentially of larger and smaller plagioclase crystals embedded in a fine dark-grey dusty-looking matrix, which may have been originally in part glassy. The rock contains frequent irregularly shaped flakes of biotite, which would appear to be secondary, and are often included in the felspars. The form of the magnetite frequently suggests that it is intimately associated with the pseudomorphosis of a ferromagnesian mineral. In the thinner portions of the section the groundmass is seen to be full of minute dark greenish granules, probably pyroxene. Is it possible that this rock could have been affected by contact metamorphism?

(*b*) *Felsitic Rocks.*

[8883.] Acid lava, including a more basic fragment, Craig Rossie, opposite to Upper Coul, east from Auchterarder, Perthshire. A purplish rock showing porphyritic white felspars and some flakes of biotite. The felspar is much decomposed, but some proportion of it certainly appears to be orthoclase. The biotite is poorly represented in the slide, and is usually more or less obscured by secondary magnetite. A few small corroded quartz-grains are present, but not in sufficient quantity to rank as an essential constituent. The groundmass consists of smaller idiomorphic felspars in a felsitic matrix, containing ill-defined patches of quartz. There are also some irregular vesicles containing silica. The darker portion of the section—probably representing a caught-up fragment—is too much altered for satisfactory recognition. Its margin is sharply defined. It appears to have been to some extent silicified, while portions are obscured by magnetite dust. It does not resemble any of the more basic rocks from this district that I have seen.

[8884.] Craig Rossie (lowest sheet), opposite Upper Coul, Auchterarder. A fairly similar rock to the last, but paler in colour. The felspar phenocrysts include both simply-twinned crystals and individuals twinned on the albite plan, probably indicating orthoclase and an acid plagioclase. A few small rounded quartz-grains are present, but their proportion is insignificant. Biotite flakes are more numerous than in the preceding rock, and frequently show replacement by iron-oxide in the manner characteristic of the biotites in the hornblende-andesites and trachytes. The groundmass contains numerous small idiomorphic felspars embedded in a matrix consisting of a confused aggregate of microcrystalline quartz and felspar and felsitic material.

[8885.] Craig Rossie, Auchterarder. Similar in composition to the last two, but showing a well-defined flow-structure. Plagioclase is probably slightly in excess of orthoclase. The biotite is almost entirely replaced by iron-ore. The groundmass is crowded with more or less lath-shaped felspars, the matrix in which they lie being compact and felsitic, and showing a banded structure due to flow, well seen in the hand-specimen.

[8886.] Acid lava, Craig Rossie. A very similar rock to 8884. The felspar phenocrysts are very numerous, and an acid plagioclase would certainly appear to be the predominant type. The groundmass is mainly felsitic.

[8887.] From one of the ellipsoidal kernels filling a cavity in the lava of Craig Rossie. A compact siliceous rock, consisting of whitish and cream-coloured portions. The latter appears to consist of an exceedingly minute quartz-aggregate, throughout which are scattered ill-defined flecks of a reddish material, probably iron-ore. The whiter portion is a less fine-grained quartz-mosaic. Secondary silicification appears to have taken place.

[8889.] From a sheet interstratified among sandstones and conglomerates, west point of Wormit Bay, Tay Bridge. Pale reddish felsitic lava. The microscope shows felspar crystals (phenocrysts) which are probably orthoclase, but owing to decomposition cannot be identified with certainty, in a brownish felsitic matrix, showing a tendency to flow-structure.*

[8782.] Stone in bedded agglomerate, Craigend, Monk's Grave, east from Rumbling Bridge. A pale felsitic rock with banded structure, due to flow. The microscope shows more or less tabular decomposed felspars with their longer axes arranged parallel to the banding of the rock, and an occasional flake of altered biotite, in a felsitic base, consisting of alternating lighter and darker bands.

[8888.] Stone from conglomerate, railway cutting, near Wormit, Tay Bridge. Consists of numerous phenocrysts of plagioclase, and possibly also some alkali-felspar, but in no great quantity, and an occasional bleached biotite flake, in a felsitic base in which small felspar microlites may be recognised. This is a rather less acid type than the Craig Rossie lava.

[8892.] Block in conglomerate, Wormit, Tay Bridge. Shows a few conspicuous felspar phenocrysts, some of which are simply twinned and appear to be orthoclase, while others rather suggest an acid plagioclase. The groundmass consists of numerous small idiomorphic felspars, mostly showing albite-twinning, and some irregular patches and vesicles filled with quartz, in a felsitic base showing a rude flow-structure. An occasional biotite flake may also be observed.

[8893.] Block in conglomerate, near tunnel, Wormit, Firth of Tay. The microscope shows phenocrysts of clear felspar, most of which shows albite-twinning, probably representing an acid plagioclase (oligoclase) and a few flakes of biotite, in a felsitic matrix containing small idiomorphic felspars and irregular elongated vesicles filled with crystalline quartz. The arrangement of the vesicles indicates flow-structure. These blocks rather resemble some portions of the Craig Rossie rock.

[8890.] From thin bed of felspathic sandstone in conglomerate

* The following six specimens show that these more acid rocks were true lavas contemporaneously ejected among the conglomerates and sandstones, which contain fragments and are sometimes entirely composed of their detritus.—A. G.

immediately east from the south end of Tay Bridge. A pale pinkish fine-grained rock showing lamination. Under the microscope the rock is seen to be almost entirely made up of small fragments of felsitic material, no doubt derived from some of the more acid lavas, such as No. 8889. A few small rounded quartz-grains and felspars may be recognised. There are also some darker fragments obscured by iron oxide. Most of the fragments appear to be more or less rounded, though many are quite angular.

[8891.] Felspathic sandstone, top of bank a little west of Jock's Hole, Wormit Bay, near Tay Bridge. Consists of numerous more or less angular grains of quartz, felspars, small colourless and greenish flakes, probably representing altered biotite, and fragments of lava, in a fine dusty-looking matrix, probably consisting for the most part of volcanic material. The rock is traversed by occasional narrow veins of calcite.

II. Sills connected with the Andesite Lavas.

[8767.] From a sill at its junction with an andesite lava, railway cutting south from where line crosses the Farg, Glen Farg. The contact between the two rocks is exceedingly sharp and well defined. The andesite is of a basic type, contains small pseudomorphs after idiomorphic olivine, showing the ferruginous type of alteration, and presents as its groundmass a *microlithenfelz*, which contains a considerable quantity of iron-ore. The sill appears to represent the same magma as this lava, there being a strong family likeness between the two rocks. It shows a well-marked chilled edge at the contact. Besides the plagioclase phenocrysts, which are similar to those of the lava, we find olivine-pseudomorphs and a few more or less rounded grains of augite. The olivine-pseudomorphs show a thick border of deep red iron-oxide and irregular cracks filled with the same material. They probably represent a ferruginous variety (hyalosiderite). The reddish coloured portion often shows a distinct pleochroism. The rock might be termed an intrusive *Olivine-Augite-Andesite.*

[8769.] From the same sill as the last. The specimen is from the more central portion of the sill. The microscope shows plagioclase phenocrysts, granular aggregates of almost colourless augite, and pseudomorphs after idiomorphic olivine, showing a deep black border and irregular cracks filled with iron-oxide. The olivine occasionally occurs as inclusions in the augite. The groundmass consists of smaller lath-shaped plagioclases, augite grains, magnetite, and some greenish decomposition products. The rock is evidently of a basic type, and approaches the porphyritic basalts.

[8878.] Sill, White Craig, above Newburgh, Fife. The largest sill yet observed in the Ochil Hills (*see* p. 30). This rock is very similar to some of the lavas above described. It consists essentially of small lath-shaped felspars, showing flow-structure, altered pyroxene grains, and magnetite granules. Phenocrysts are scarce, and consist of usually clearer felspars than those of the main mass of the rock.

[8879.] Quarry, Pairnie, east from Auchterarder, Perthshire. This is perhaps a slightly more acid type of sill than the preceding. The felspars of the earlier generation are of shorter and more tabular habit, resembling oligoclase, and the ferromagnesian constituents are apparently scarce and obscured by decomposition. The groundmass appears to be mainly felspathic.

[8775.] Sill or intrusive boss, above Pottie Mill, Glen Farg. This rock presents no very marked distinction between phenocrysts and groundmass. It consists essentially of larger and smaller more or less idiomorphic plagioclases, amongst which a more acid felspar appears to be sometimes present, a few small bastite-pseudomorphs after a slightly pleochroic enstatite, and some brownish interstitial matter. Magnetite is accessory. The rock appears to be allied to the enstatite-bearing intrusive series (8770 and 8772), but is much poorer in the ferro-magnesian element, and rather suggests a porphyrite modification, of rather more acid tendency, of the same group of rocks.

III. Bosses.

[8770.] From the boss at Corb Bridge, five miles south from Dunning. A medium-grained dark purplish rock of doleritic texture. Under the microscope the rock is seen to be composed essentially of plagioclase and enstatite. The plagioclase is more or less idiomorphic, and resembles that characteristic of the enstatite-andesites already noticed. The enstatite has a fibrous structure from alteration, and occurs in groups and isolated, more or less corroded, grains, but occasionally shows crystal form. It is distinctly pleochroic (yellowish green to pale green). Augite appears to be almost entirely absent. There is a very small quantity of interstitial quartz and unstriped felspar. Magnetite is accessory. This rock is allied to hyperite and enstatite-diorite. It resembles in many respects the quartz-norites (Teller and von John) of Klausen in the Tyrol, and is doubtless the deep-seated representative of the enstatite-andesites. It might perhaps be termed hyperite or norite (in Rosenbusch's sense), since it is composed essentially of plagioclase and a rhombic pyroxene.

[8772.] Boss, south from Damhead. This rock is slightly more acid than 8770, the proportion of ferromagnesian constituents being decidedly smaller. There is a high proportion of plagioclase (probably labradorite), which is for the most part clear and more or less idio-morphic. Besides the ordinary albite lamellation, pericline-twinning may sometimes be observed. Some crystals also exhibit a zonal structure. The ferromagnesian minerals lie associated together in groups of irregular grains, and consist of augite, altered enstatite, and a small quantity of biotite. The latter is very strongly dichroic—pale straw colour to a deep rich red brown. Occasionally, in the interspaces between the plagioclase crystals, small patches of unstriped felspar, probably orthoclase, may be seen; while a small quantity of quartz occurs interstitially, and is usually associated with the orthoclase. Magnetite and apatite are accessories. The rock is closely allied to the enstatite-diorites and quartz-norites.

IV. Dykes.

[8773.] Dyke, below Corb Bridge, five miles south from Dunning. This belongs to the more acid or intermediate intrusive series. A dark brownish rock of rather compact appearance, with small felspar phenocrysts and dark greenish patches. It is rather too decomposed for satisfactory description. The microscope shows both larger and smaller felspar phenocrysts, greenish pseudomorphs after a ferro-magnesian mineral, and irregular vesicles, in an ill-defined brownish

felsitic matrix containing minute lath-shaped felspars. The felspars of the earlier generation are mostly plagioclase; some unstriped individuals also occur, possibly representing orthoclase. The ferromagnesian mineral is too much altered for precise determination; some of the pseudomorphs suggest a rhombic pyroxene. A greenish material is also found in some of the vesicles together with silica. As plagioclase is the predominant felspar, the rock may be termed a *Porphyrite*.

[8776.] Dyke in the boss at Corb Bridge, south from Dunning. A dull reddish porphyritic rock, with phenocrysts of felspar and a green mineral suggesting hornblende. The microscope shows numerous idiomorphic felspars, crystals and crystalline aggregates of altered hornblende, and accessory magnetite grains in a brown felsitic matrix. A few small granular aggregates of quartz are present, but appear to represent infilled vesicles. Among the felspars, individuals of shorter and more stumpy habit may be recognised—probably orthoclase—as well as plagioclase. The latter, however, is evidently in excess, so that the rock is more nearly allied to the hornblende-porphyrites than to the felspar-porphyries.

[8780.] Dyke below roadside, north of Corb Bridge. The microscope shows numerous small phenocrysts of felspar, some of which is apparently orthoclase, in a compact felsitic matrix. The structure of the ground-mass is not uniform throughout, but appears to consist in part of small bodies like spherulites (microspherulitic), and in part somewhat resembles perlitic cracking. The two portions are sometimes rather sharply marked off from one another. The original unaltered rock was possibly allied to pitchstone.

[8881.] Dyke in sandstone quarry, east from Corbiehill, south of Balmerino. The rock consists essentially of elongated crystals of plagioclase (probably labradorite) and greenish irregularly-shaped pseudomorphs after pyroxene, possibly in part representing enstatite. The rock resembles in structure and general appearance some of the plagioclase-enstatite boss-intrusions. *Hyperite* (?), compare No. 8775.

[8784.] Dyke, roadside near Ferniehill, Queich Water (Sheet 39). The microscope reveals numerous felspar phenocrysts, flakes, and hexagonal plates of biotite, and a few small quartz-grains in a felsitic base, showing a rude flow-structure. The felspar is too decomposed for determination; from its short stumpy habit probably a good deal of it is orthoclase. The rock might be termed a *Biotite-Felspar-Porphyry*, or *Orthophyre*.

[8785.] Dyke, same locality. Shows similar features under the microscope as the preceding.

General Remarks.

The rocks from the Ochil Hills here examined fall into two well-marked divisions—the one more basic, the other more acid, with one or two transitional types, each division being characterised by both extrusive and intrusive groups.

The most typical rocks of the more basic division are enstatite-andesites, some of which closely resemble the more basic varieties of the Lorne series. They appear to be slightly more basic than the typical Cheviot andesite. Olivine-bearing varieties also occur, in which olivine takes the place of enstatite, and these are also found at a low horizon among the Lorne rocks.

Among the andesitic lavas a fairly basic type seems to predominate, in which pseudomorphs after olivine may occasionally be recognised. The groundmass in some of the coarser varieties becomes holocrystalline, but is usually of the more typically andesitic type, and contains a varying proportion of glassy base. Small pyroxene grains are usually present in the groundmass, as well as the characteristic lath-shaped plagioclases. An approach to the trachytic type of groundmass is also sometimes seen, but the presence of pyroxene distinguishes it from the groundmass of a typical trachyte. Flow-structure is often indicated by the orientation of the small plagioclase laths. Some of the rocks are crowded with conspicuously porphyritic felspars, while others again appear to be very poor in felspars of the earlier generation.

Among the more acid lavas the Craig Rossie rock is decidedly characteristic. It appears to be intermediate in character between andesite and rhyolite, with affinities to dacite and trachyte. The rock doubtless represents the more acid expression of the andesitic magma. The presence of orthoclase and the occasional occurrence of quartz-grains ally the rock to the rhyolites and liparites; the groundmass is also rather of the devitrified rhyolitic type than the trachytic. The orthoclase, however, does not appear to exceed the plagioclase in amount, and plagioclase decidedly predominates over orthoclase in some of the more acid lavas from near Wormit [8888], thereby proclaiming the andesitic relationships of the rocks.

Several of these more acid lavas resemble some of the banded felsitic rocks of Lorne.* The latter are probably rhyolitic forms of a somewhat acid biotite-andesite, allied to trachyte. The typical "trachytic" groundmass, however, is not seen in either the Lorne or the Ochil rocks. Among the intrusive rocks we have some porphyrites, though not typical; but the majority belong rather to the orthoclase-porphyries or orthophyres. The porphyritic structure is often not very conspicuous.

The intrusive bosses are interesting, and evidently represent the more deep-seated phase of the magma from which the lavas were derived. They appear to vary somewhat in the relative proportion of the different constituents. On the whole, they may be said to belong to a group of enstatite-diorites, closely related to the quartz-norites of Teller and von John, occurring at Klausen in the Tyrol, which are really of a more intermediate type (generally containing a certain proportion of quartz and alkali-felspar) than the truly basic norites (in Rosenbusch's sense). They may also be compared with the hyperites described by Mr. Teall as associated with the granite mass of Loch Dee.† This would be a petrological point in favour of the Old Red Sandstone age of the Galloway granites.

I suppose the granophyric enstatite-diorite mapped by Mr. Peach, above Tillicoultry, and the hyperite from near Dunning, examined by Mr. Watts, belong to the same group.‡ In connection with the above rocks I have used the term "enstatite" as applying rather to the *group* of rhombic pyroxenes than to any particular species. In many cases, owing to the distinct pleochroism, the mineral probably belongs to a more ferriferous type than enstatite proper.

Among the dykes and sills the great intrusive sheet of Newburgh closely resembles many of the andesitic lavas (8878), while 8879

* Summary of Progress of Geological Survey for 1898, p. 84.

† Ann. Rep. Geological Survey for 1896, p. 41.

‡ Ancient Volcanoes Great Britain, Vol. I., pp. 277, 278.

appears to be of a slightly more acid type. The dyke (8881) is a peculiar rock, and appears to be allied to the boss-like intrusions, consisting of plagioclase and enstatite, already noticed from other parts of the district.

Notes on some Volcanic Rocks from the Lower Carboniferous Series at the West End of the Cleish Hills. By Herbert Kynaston, B.A.*

[8774.] Above waterfall, Georgeton Burn, south-east of Rumbling Bridge, west end of Cleish Hills. A dark-grey very fine grained rock weathering rusty brown, and showing a few phenocrysts of felspar. The microscope shows phenocrysts of a clear glassy felspar, and a few altered pyroxene (?) grains in a groundmass of felspar microlites, pyroxene granules, and magnetite. The clear felspar sometimes shows a fine striation (which can be seen with the lower nicol only) at right angles to the normal albite lamellation. Possibly this represents pericline-twinning. The albite lamellæ are often wanting in some parts of the crystal, and present in others. Occasionally they are not seen at all, and twinning on the Carlsbad plan is sometimes present. Most of the individuals are traversed by irregular cracks, which in the more weathered portion of the rock show ferruginous staining. On the whole the rock appears to be too basic for a trachyte. The groundmass and the mode of weathering suggest rather that of a basalt.

[8778.] Scaur Hill, west end of Cleish Hills, east of Rumbling Bridge, Fife. A purplish felsitic rock, showing small pink felspars and a well-marked flow-structure. Under the microscope one portion of the slide is seen to possess flow-structure, while the other portion is brecciated. The unbrecciated portion shows brownish, turbid, more or less tabular crystals of simply twinned orthoclase, having a well-marked cleavage embedded in a felsitic matrix showing fluidal structure. Small irregular grains of quartz are also present, and some irregular patches resembling detached fragments. The brecciated portion shows angular fragments of the same rock, broken felspars and quartz-grains, without apparently any definite arrangement. The rock is more nearly allied to rhyolite than trachyte.

[8781.] Scaur Hill, south-east of Rumbling Bridge, Fife. The rock is much decomposed, and similar to 8778, but shows no marked flow-structure or any signs of brecciation.

[8783.] Below waterfall, Georgetown Burn, Hardiston, east of Rumbling Bridge. Compact felsite, with small pink felspars. The rock belongs to the same group as 8781 and 8778. The section shows felspars of tabular habit in a felsitic base, containing some calcareous alteration products. The felspars are more or less turbid from alteration, but sometimes partially clear (sanidine), and show Carlsbad twinning. The pink colour of the felspar in the hand specimen, which appears brown in thin section, is probably due to infiltration of iron-oxide along the cleavage cracks.

* These rocks form a remarkable group in the Calciferous Sandstone Series, and their general characters and stratigraphical relations are enumerated in Chapter V. The specimens examined and described by Mr. Kynaston come from the band of lavas which overlies a thick belt of fine tuffs and forms the uppermost part of the group. As already stated, the numbers within square brackets refer to the microscopic slides in the collection of the Geological Survey.—A. G.

[8777.] Block in conglomerate overlying felsitic lava, Georgetown Burn, Hardiston, Fife. A decomposed felsitic rock showing small phenocrysts of altered felspar, some of which show simple Carlsbad twinning (orthoclase), in a brownish patchy and discoloured felsitic base. A good deal of free silica has been liberated in the groundmass. The darker discoloured patches appear to be due to ferruginous staining. They sometimes enclose clearer areas containing a clear mineral, possibly tridymite. The rock is apparently an altered felsitic lava.

[8779.] From block in conglomerate overlying felsitic lava, Georgetown Burn, above Hardiston, Fife. The rock is very similar to 8777, and shows the discoloured patches, due to infiltration of iron-oxide, more distinctly. The porphyritic felspars are more numerous and clearer, but evidently much decomposed, and give merely a fine dark dusty-looking polarisation between crossed nicols. The angles of the crystals are more or less rounded from corrosion. The dark irregular patches usually enclose a clear mineral, with a low refractive index and weak double refraction. The appearance is that of colourless patches broken up by a network of deeply stained cracks. Some portions behave isotropically, while others give merely greyish polarisation tints. This suggests tridymite. Possibly the patches represent infilled drusy cavities.

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PART IV.

JOURNAL OF BLAIRHALL DIAMOND BORE MADE BY THE COLTNESS IRON COMPANY, LD., ON NORTH SIDE OF ROAD, ABOUT 200 YARDS EAST OF RENNIE'S WALLS, AND A MILE WEST OF OAKLEY STATION.

	Fms.	Ft.	In.
Surface, -	1	5	0
Fakes and blaes,	0	3	6
Faky sandstone,	2	0	0
Hard sandstone,	0	4	6
Fakes and do.,	1	0	6
Fakes, -	0	2	4
Fakes and blaes,	1	4	2
Broken do. and blaes,	0	3	6
COAL ("Coal Crumpy"),	0	3	2
Fakes,	0	0	1
Fireclay,	0	0	2
Fakes, -	0	2	2
Sandstone,	0	3	8
COAL, - -	0	0	10
Coaly blaes,	0	0	9
Faky fireclay,	0	1	1
Fakes,	0	3	3
Sandstone,	0	2	6
Coarse sandstone,	5	1	1
WASTE, -	0	1	0
Fireclay,	0	1	6
Sandstone,	0	1	4
Fakes and blaes,	0	2	6
Sandstone,	0	4	0
Fakes, -	0	0	5
Blaes,	0	0	5
COAL, -	0	1	8
Dark sandstone,	0	0	3
Sandstone,	0	0	9
Fakes, -	0	1	2
Blaes and ironstone balls,	0	2	7
Black coaly blaes,	0	0	4
Light fireclay,	0	0	5
COAL,	0	0	4
Blaes,	0	0	3
Fakes and sandstone,	0	3	6
Blaes, -	0	1	1
Ironstone-rib,	0	0	1
Irony fake,	0	0	1
Dark sandstone,	0	1	0
Fakes,	0	1	8
Fakes and sandstone,	0	3	2
Hard sandstone,	0	1	5
Fakes,	0	3	8
Fireclay,	0	0	8
Hard sandstone,	0	1	0
Carry forward,	23	0	6

	Fms.	Ft	In.
Brought forward,	23	0	6
Fakes and sandstone,	0	1	5
Fakes and blaes,	0	0	11
Limestone fakes,	0	0	4
Dark fakes, -	0	1	1
Sandstone,	0	2	6
Faky fireclay,	0	2	2
Sandstone fakes,	0	4	0
Sandstone,	0	1	11
Fakes,	0	5	4
Sandstone,	0	3	6
Dark blaes, -	0	1	0
Dark fakes and balls, and coal-strains, -	0	0	9
Faky sandstone,	0	3	5
Black blaes,	0	0	3
IRONSTONE,	0	0	1
Black blaes,	0	0	4
COAL, -	0	0	7
Faky sandstone,	0	3	10
Fakes and blaes,	0	3	0
Faky sandstone,	0	4	4
Blaes and iron-balls, -	0	3	11
Fakes and sandstone,-	0	1	9
Blaes,	0	1	7
COAL, -	0	0	7
Coaly blaes, -	0	0	2
Dark fireclay and balls,	0	2	6
Fakes and blaes,	0	4	0
COAL, - -	0	0	4
Fakes and blaes,	0	1	4
Faky sandstone,	0	4	0
WASTE,	0	2	2
Faky sandstone,	0	1	8
Sandstone, -	1	3	7
Fakes, -	0	2	5
Black blaes and iron-ribs,	0	2	4
Ironstone,	0	0	1
Black blaes,	0	0	3
Ironstone, -	0	0	6½
Fakes,	0	0	2½
Coaly blaes,	0	0	5
COAL, - - -	0	0	9
Faky fireclay and balls,	0	4	6
Hard fakes and sandstone,	0	3	0
Fakes and blaes,	0	3	8
Carry forward, -	38	3	0

	Fms.	Ft.	In.	
Brought forward,	38	3	0	
Sandstone (hard),	0	4	11	
Fakes,	0	1	0	
Blaes,	0	2	3	
COAL, - - - -	0	0	6	
Fireclay and coal-strains,	0	0	3	
Fireclay,	0	0	8	
Sandstone,	0	1	8	
Fakes,	0	0	4	
COAL, -	0	0	7	
Blaes and coal-strains,	0	0	2	
Fakes and blaes, -	0	2	0	
Coal and blaes,	0	1	2	
Fakes,	0	3	5	
Sandstone,	0	3	11	
Faky sandstone,	0	5	10	
Fakes,	0	3	10	
Blaes,	0	0	11	
COAL, -	0	1	5	
Fireclay,	0	0	3	
Fakes and sandstones,	3	3	3	
Dark fakes,	0	0	2	
COAL,	0	0	7	
Fakes,	0	1	9	
Blaes and balls, -	0	1	8	
Hard fake,	0	0	9	
COAL, -	0	0	2	
Fakes and sandstone,	0	3	8	
Blaes,	0	1	1	
COAL, -	0	0	4	
Blaes, -	0	0	7	
Fakes and sandstone,	1	0	9	
Faky blaes and balls,	1	0	3	
Hard sandstone, -	0	0	6	
Faky blaes, -	0	0	5	
COAL, -	0	0	8	
Coal and blaes,	0	0	2	
Blaes, -	0	0	7	
Fakes and blaes,	0	5	1	
COAL, -	0	0	4	
Fakes, -	1	1	7	
Blaes and balls,	0	3	9	
Fakes and blaes,	0	5	8	
COAL, -	0	0	6	
Fakes and sandstone,	0	3	6	
Fakes and blaes, -	0	3	6	
Hard sandstone,	1	2	10	
Fakes and blaes,	0	3	9	
Blaes and balls,	1	0	6	
Limestone fakes, -	0	0	3	"INDEX" LIMESTONE.
Blaes, - -	0	0	5	"INDEX" LIMESTONE.
Limestone fakes, -	0	1	2	"INDEX" LIMESTONE.
Fakes and blaes, and balls (limy), -	2	5	0	"INDEX" LIMESTONE.
Fireclay, blaes, and balls, -	2	4	0	"INDEX" LIMESTONE.
Limestone fakes, .	0	1	2	"INDEX" LIMESTONE.
Limestone, - -	0	0	4	"INDEX" LIMESTONE.
Blaes and balls,	2	2	8	
COAL, -	0	1	2	
Fireclay, -	0	1	9	
Fakes and fireclay,	0	5	3	
Carry forward,	70	1	7	

	Fms.	Ft.	In.	
Brought forward,	70	1	7	
Fakes and sandstone,	1	1	7	
Fakes and fireclay, -	0	2	5	
Sandstone (hard),	0	2	8	
Fakes, - -	0	2	7	
Blaes,	0	1	4	
COAL, - -	0	1	0	
Fakes, fireclay, and balls,	1	0	10	
COAL, - -	0	1	4	
Dark sandstone (soft),	0	4	6	
Light do., do.,	1	5	4	
Soft coal and blaes,	0	1	0	
Fakes,	0	0	9	
COAL, -	0	0	3	
Fakes and blaes,	1	1	6	
Hard fakes,	0	0	4	
Fakes and blaes,	0	1	5	
Sandstone,	3	2	7	INZIEVAR OR BLAIRHALL BLACK-BAND.
Parrot Coal,	0	0	4	INZIEVAR OR BLAIRHALL BLACK-BAND.
Ironstone (Black-band),	0	1	3	INZIEVAR OR BLAIRHALL BLACK-BAND.
Blaes, - -	0	0	3	INZIEVAR OR BLAIRHALL BLACK-BAND.
Ironstone (Black-band),	0	0	1	INZIEVAR OR BLAIRHALL BLACK-BAND.
Parroty blaes,	0	0	3	INZIEVAR OR BLAIRHALL BLACK-BAND.
Fakes, -	1	1	9	
Faky blaes,	1	1	8	
Fakes and sandstone,	1	0	9	
Fakes and blaes, -	0	1	0	
COAL, -	0	0	5	
Fakes,	0	0	0½	
COAL, -	0	0	5½	
Blaes and balls,	0	3	10	
Fakes,	0	0	4	
Blaes,	0	0	3	
COAL,	0	1	5	
Fireclay and blaes,	0	0	9	
Fakes and sandstone,	2	5	6	
Fakes and blaes,	0	1	11	
Blaes, -	0	4	4	
Ironstone-rib,	0	0	1	
Blaes, -	0	0	3	
Ironstone-rib,	0	0	1	
Blaes, -	0	0	1	
COAL (BLAIRHALL MAIN COAL), - -	0	2	10	
Fireclay and coal-strains,	0	1	2	
Fakes,	0	0	8	
COAL, -	0	0	3	
Fakes,	0	0	8	
Blaes,	0	3	8	
Fakes and sandstone,	2	2	11	
Blaes, -	0	0	3	
Parroty blaes,	0	0	1	
COAL, - -	0	0	3	
Fakes and blaes,	0	2	11	
COAL, - -	0	0	5	
Soft fireclay,	0	0	2	
Faky fireclay,	0	4	3	
Sandstone,	4	2	5	
Blaes,	0	0	5	
COAL,	0	0	8	
Carry forward,	102	0	1	

	Fms.	Ft.	In.
Brought forward,	102	0	1
Blaes,	0	1	10
Hard fake,	0	0	8
Blaes,	0	5	9
Coaly blaes,	0	0	3
COAL,	0	0	7
Blaes,	0	0	3
Sandstone fakes,	0	5	3
Sandstone,	0	4	4
Fakes,	0	0	4
Coarse sandstone,	2	2	0
Fakes,	0	1	2
Blaes,	0	4	10
Blaes and ironstone,	0	0	2½
Ironstone,	0	0	1½
Black faky blaes,	0	4	11
IRONSTONE,	0	0	1
Coaly blaes,	0	0	2½
COAL,	0	0	4½
Blaes and balls,	0	1	8
Blaes,	0	5	10
Fakes,	0	0	7
Fakes and balls,	0	1	1
IRONSTONE,	0	0	6
Fakes,	0	1	7
Blaes,	0	0	6
Brown faky fireclay, spotted,	0	0	2
COAL,	0	0	10
Coaly blaes,	0	0	0½
COAL,	0	1	1½
Light brown stone,	0	0	2
COAL,	0	0	2
Faky fireclay,	0	0	7
Faky sandstone,	2	0	8
Fakes and blaes,	0	2	2
Blue blaes,	0	2	3
Black blaes,	0	0	6
Irony fake,	0	0	1
Black blaes,	0	3	2
IRONSTONE (Black-band),	0	0	1
Parroty blaes,	0	0	3
IRONSTONE (Black-band),	0	0	5
Fakes,	0	0	11
IRONSTONE (Black-band),	0	0	7½
COAL,	0	0	3
Fireclay,	0	0	9
Fakes and fireclay and balls,	0	4	0
Fakes,	0	4	4
Sandstone,	2	3	7
Blaes and coal-strains,	0	0	9
Fakes,	0	0	2
Fireclay and coal-strains,	0	0	10
Fireclay,	0	0	4
Fakes,	0	0	5
Blaes,	0	0	9
COAL (slaty),	0	0	8½
COAL and Blaes,	0	0	2
Fireclay,	0	0	5
Fakes,	3	4	10
Blaes,	0	1	7
Carry forward,	124	5	1

	Fms.	Ft.	In.
Brought forward,	124	5	1
COAL,	0	0	8
Coaly blaes,	0	0	2
Blaes,	0	0	7
Coaly blaes,	0	0	3
Blaes,	0	1	2
Coaly blaes,	0	0	3
Fakes,	0	1	8
Coaly blaes,	0	0	4
COAL,	0	0	7
Fake,	0	0	1
Coaly blaes,	0	0	1
IRONSTONE,	0	0	6
Blaes,	0	1	3
COAL,	0	0	2
Sulphury ball (ironstone),	0	0	2
COAL,	0	0	3
Brown stone,	0	0	0½
COAL,	0	1	1½
Fake (coaly),	0	0	1½
COAL,	0	2	1½
Fakes,	0	2	11
Hard sandstone,	0	2	8
Fakes,	1	0	7
Sandstone,	0	2	1
COAL,	0	0	4½
Coaly blaes,	0	0	0½
COAL,	0	0	5
Coaly blaes,	0	0	1
Blaes,	0	0	4
Fakes,	0	0	2
Ironstone-rib,	0	0	1
Fakes and blaes,	0	1	8
COAL,	0	1	4
Fakes,	0	5	7
Fakes and sandstone,	0	3	6
Fakes and blaes,	1	0	9
Hard sandstone,	1	1	0
Faky do.,	0	2	7
Fakes,	0	2	3
Blaes,	0	0	11
COAL,	0	0	2
Ironstone (Black-band),	0	0	2½
COAL,	0	0	0½
Blaes (black),	0	1	1
COAL (Parrot, coarse),	0	1	3
Ironstone (Black-band),	0	0	11½
Black blaes,	0	0	0½
Faky fireclay,	0	1	11
Fakes,	0	5	9
Dark blaes,	0	2	6
Ironstone (Black-band),	0	0	1
Blaes,	0	0	4
Ironstone (Black-band),	0	0	1
Blaes (irony),	0	0	3
Ironstone (Black-band),	0	0	3
COAL,	0	0	2
Fakes and fireclay and balls,	0	1	8
Fakes,	3	3	4
COAL,	0	0	9
Fireclay,	0	1	8
Carry forward,	141	2	6

	Fms.	Ft.	In.
Brought forward, -	141	2	6
Sandstone fakes,	0	1	7
Fakes and blaes,	0	0	8
Hard faky sandstone,	0	2	9
Fakes,	0	1	8
Blaes,	0	5	0
Hard fake, -	0	1	5
Hard faky sandstone,	1	0	7
Faky blaes, -	0	3	7
COAL, - -	0	0	5
Coaly blaes,	0	0	2½
Hard sandstone,	0	0	3
COAL, - -	0	2	2½
Coaly blaes,	0	0	2
Fireclay, -	0	0	1
Hard faky sandstone,	1	0	8
Fakes, -	0	1	4
Blaes, -	0	1	7
PARROT COAL (irony),	0	0	4
IRONSTONE (Black-band), -	0	0	6
PARROT COAL, -	0	0	4
COAL, -	0	1	8
Blaes, - -	0	1	1
Fakes,	0	1	4
Dark blaes,	0	5	9
IRONSTONE, -	0	0	2
Fireclay,	0	0	6
Fakes, -	0	2	10
Hard faky sandstone,	2	3	0
Faky sandstone,	0	4	6
Fakes and blaes,	1	1	0
Hard broken sandstone,	1	0	8
Faky fireclay and balls,	1	1	6
Fakes,	0	1	0
Sandstone, -	1	1	0
Fakes and fireclay,	0	4	9
Coarse sandstone,	4	0	8
Hard sandstone,	0	3	9
Softer sandstone, -	1	4	6
Fakes, - -	0	2	9
Blaes, - -	0	5	6
Fakes and sandstone,	1	4	0
Fakes, -	0	2	3
Dark blaes,	2	1	0
Coaly blaes (burnt), -	0	0	4
Whinstone, -	1	5	11
Black blaes,	0	0	1
COAL (burnt, hard), - -	0	2	5
Blaes, - -	0	5	6
Fakes, - -	0	2	1
Blaes, - -	0	2	7
Coaly blaes,	0	1	9
COAL, - - -	0	0	1
Coaly blaes, -	0	0	2
COAL, - - -	0	0	9
Slaty coal, -	0	0	5
COAL, - - -	0	3	7
Coaly blaes, -	0	0	4
Faky fireclay,	0	1	7
Fakes,	0	2	3
Blaes with coal-strains,	0	1	6
COAL, - -	0	0	9
Carry forward, -	177	1	1

	Fms.	Ft.	In.
Brought forward,	177	1	1
Stone, -	0	0	2
COAL, -	0	1	6
Daugh, - -	0	0	0½
COAL, -	0	1	10½
Faky fireclay, .	0	0	5
Fakes,	0	2	0
Blaes,	0	1	3
Fakes,	0	1	7
Blaes,	0	2	9
COAL,	0	0	1
Fireclay,	0	0	4
Fakes,	0	0	11
Sandstone,	1	0	6
Fakes and blaes,	0	3	0
Dark sandstone,	2	0	6
Hard sandstone fakes,	0	3	4
Calmy whinstone,	0	0	11
Whinstone,	17	2	2
Blaes, -	0	0	1
COAL (burnt), - -	0	0	3
Dark fakes, - -	0	1	4
Coaly blaes,	0	0	2
Blaes,	0	0	9
Fakes, -	0	0	8
Hard sandstone fakes,	0	5	9
Fakes and blaes, -	0	5	0
Blaes, -	0	2	8
IRONSTONE, -	0	0	2
Black blaes, -	0	0	4
Whinstone (light),	0	1	7
COAL (burnt), -	0	0	7
COAL mixed with whinstone,	0	0	6
Fakes,	0	0	3
Sandstone,	0	4	8
Fakes and blaes,	0	2	0
Blaes, -	0	1	11
Dark Fakes,	0	0	6
COAL, -	0	0	5
Coaly blaes, - -	0	0	2
Blaes and balls (ironstone),	0	4	5
Fakes,	0	3	8
Sandstone, -	2	0	6
Fakes and sandstone,	1	1	8
Fakes and blaes, -	0	3	1
Black blaes,	0	0	9
COAL, - -	0	1	10
Fake, -	0	0	1½
COAL, -	0	1	6
Fake,	0	0	1½
COAL, - -	0	1	6
Sandstone, -	1	1	5
Do. and fakes, -	0	4	2
Dark fakes and blaes,	1	3	0
Ironstone (Mussel-band),	0	0	0½
Dark fakes and blaes,	2	1	6
Faky sandstone, -	0	1	7
Hard do.,	3	2	0
Fakes and do., -	0	5	3
Fakes and blaes,	0	4	0
Blaes and balls, -	1	1	11
Ironstone balls, - -	0	0	2
Carry forward, -	224	2	4½

	Fms.	Ft.	In.
Brought forward,	224	2	4½
Dark blaes,	0	4	4
Ironstone-rib,	0	0	1
Dark blaes,	1	0	0
Irony fake,	0	0	1
Blaes,	0	1	11
Hard fakes,	0	0	9
Blaes,	0	1	9
Hard fakes,	0	1	9
Blaes,	1	0	4
Dark fakes,	0	3	9
Hard fakes,	0	0	10
Dark fakes,	0	1	5
Black blaes,	0	4	1
Hard fakes,	0	0	6
Dark blaes,	0	2	1
Hard sandstone,	2	2	11
Sandstone fakes (hard),	0	4	8
Hard sandstone,	1	3	5
Hard fakes,	0	1	10
Hard sandstone,	0	2	2
Hard fakes,	0	3	4
Hard sandstone,	5	2	4
COAL,	0	1	0
Fakes,	0	0	3
Sandstone,	3	3	7
Fakes,	0	3	0
Blaes,	2	3	0
Fakes,	0	0	6
Blaes,	0	4	2
Fakes,	0	1	1
Blaes,	0	3	4
Fakes,	0	0	3
Blaes,	0	3	10
Fakes and blaes,	0	4	0
Dark blaes (parroty),	0	0	6
PARROT COAL,	0	1	6
Blaes,	0	0	1½
COAL,	0	0	3½
Fakes and blaes,	1	0	9
Dark blaes,	0	5	1
Parroty blaes,	0	0	3
Dark blaes,	0	0	5
Fakes,	0	0	2
COAL,	0	0	2
Fireclay,	0	0	9
Fakes,	0	1	10
Sandstone,	0	1	9
Fakes and blaes,	0	1	11
Sandstone,	5	1	0
Fakes,	0	1	2
Sandstone,	0	4	1
Dark blaes,	0	0	11
Fake (irony),	0	0	3
COAL,	0	0	7
Blaes,	0	0	11
Coaly blaes,	0	0	4
Blaes,	0	0	4
Fakes,	0	2	3
Sandstone,	0	2	4
Fakes,	1	0	8
Fakes and blaes,	0	2	0
Carry forward,	263	5	0½

		Fms.	Ft.	In.
Brought forward,		263	5	0½
Fakes,		2	1	0
Fakes and sulphur balls,		0	0	4½
Fakes,		0	0	1½
Coaly blaes,		0	1	3
Dark sandstone,		1	4	3
Whinstone,		1	4	8
Black fakes,		0	1	5
Hard sandstone,		4	5	1
Fakes,		0	3	6
Blaes and balls,		3	0	7
COAL, 4″ soft on top,		0	1	2
Faky fireclay,		0	0	10
Dark blaes and balls,		0	1	9
COAL,		0	2	3
Coaly blaes,		0	0	1
COAL,		0	0	11
Faky fireclay,		0	0	8
Fakes,		0	4	2
Blaes,		0	3	8
Hard fake,		0	0	3
Fakes and blaes,		1	5	6
Hard sandstone and fake beds,		1	1	9
Fakes and blaes,		0	3	7
Hard fake,		0	0	2
Dark blaes,		0	3	8
Light fakes,		0	0	1
Irony fake,		0	0	2½
COAL,		0	0	1
COAL AND IRONSTONE,		0	0	1
COAL,		0	0	2
Fireclay,		0	0	8
Blaes with coal-strains,		0	0	10
Fakes,		0	2	10
Hard fakes,		0	0	4
Fakes,		0	0	4
Sandstone,		0	1	2
Fakes,		0	0	2
Sandstone,		5	0	6
Fakes and sandstone,		1	3	1
Dark fakes,		0	3	10
Fakes and blaes,		1	1	2
Fakes,		0	0	2
Blaes,		1	0	4
HARD STONY COAL,	FIVE-FEET COAL.	0	0	4
COAL,		0	0	11
Stone,		0	0	0½
COAL,		0	2	0½
Stone (coaly),		0	0	1
COAL,		0	0	6½
HEAVY CLOSE-GRAINED COAL,		0	0	3½
COAL,		0	0	6
Stone,		0	0	1
COAL,		0	0	11
Fakes,		0	0	8
Coarse sandstone,		0	4	6
Faky sandstone,		0	1	6
Fakes and blaes,		0	3	7
Blaes,		1	3	5
Irony fake,		0	0	1½
Carry forward,		300	3	3½

	Fms.	Ft.	In.
Brought forward,	300	3	3½
Dark blaes,	0	4	3
Sulphur-rib,	0	0	0½
Dark blaes,	0	0	10
IRONSTONE (Clay-band),	0	0	3
Black blaes,	0	2	2
COAL, - - -	0	0	5
Ironstone (coaly)	0	0	1
COAL, - -	0	1	11
Faky fireclay,	0	0	9
Fakes and blaes,	0	4	2
COAL, -	0	0	4
Fakes and blaes,	0	2	6
COAL, - -	0	0	3
Dark fakes, -	0	5	6
Sandstone (hard),	0	3	5
Fakes, - -	0	0	3
Coarse sandstone,	0	1	6
Fakes and blaes,	0	5	9
Sandstone, -	0	0	7
Fakes and blaes,	0	2	3
Blaes,	0	4	1
Irony fake,	0	0	2
Blaes,	0	0	2
Parroty blaes,	0	0	1
PARROT COAL,	0	0	1
COAL, -	0	0	8
COAL (Slaty),	0	0	8
Fakes,	0	2	3
Blaes, -	0	0	6
Coaly blaes, -	0	0	1
Faky sandstone, -	0	2	1
Blaes with coal-streaks,	0	0	7
Fakes and sandstone,	1	2	0
Fakes and blaes, -	0	4	6
Blaes, -	1	4	11
COAL (DUNFERMLINE SPLINT COAL), - -	0	3	0
Fakes,	0	0	0½
Carry forward, -	313	0	4½

	Fms.	Ft.	In.
Brought forward,	313	0	4½
Sandstone,	1	0	9½
Fakes,	0	1	8
Blaes,	1	3	4
Blaes and sulphur-ribs,	0	0	4
Black blaes, -	0	1	4
Blaes and sulphur balls,	0	0	3
Dark fakes, -	0	0	5
Blaes and sulphur balls,	0	2	11
Fakes and blaes,	0	5	2
Fakes and sandstone,	1	5	0
Calmy fakes,	0	4	6
Sandstone,	0	4	2
Fakes,	0	1	1
Whinstone,	19	3	10
Calmy fakes,	1	1	0
Blaes,	0	2	5
Fakes and sandstone,	3	1	6
Fakes and blaes,	0	3	7
Faky sandstone,	0	2	4
Fakes, -	0	4	9
Faky blaes,	1	1	0
Dark blaes,	2	1	1
COAL, -	0	1	6½
Blaes,	0	0	2½
COAL, -	0	0	3
Blaes and sulphur balls,	0	1	8
LIMESTONE (HOSIE),	1	2	0
Black blaes and balls,	0	3	5
Limy fakes, blaes, and sulphur,	0	0	9
Black blaes, -	0	1	6
Limestone mixed with blaes,	0	1	9
Sandstone,	1	2	2
Dark sandstone mixed with calm,	1	1	10
Total depth,	356	3	11

EXPLANATION OF SCOTTISH MINING TERMS.

Balls, nodular concretions; *Blaes*, argillaceous shale; *Calm*, hard white clay, often calcareous; *Daugh*, tough clay; *Fakes*, shaly or micaceous sandstone, or sandy shale; *Iron-balls*, nodules of clay-ironstone; *Iron-ribs*, thin layers of clay-ironstone; *Mussel-band*, clay-ironstone containing lamellibranch shells; *Parrot-coal*, cannel-coal, gas-coal; *Sulphur-balls*, pyritous concretions; *Whinstone*, any hard stone, but specially applied to the basalts and dolerites which occur as dykes, sills, and bosses.

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